Daylighting Modeling and Analysis

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What we will talk about today…

- Daylighting Basics
- Summary of Modeling Inputs
- Radiosity vs. Ray Tracing
- Summary of Modeling Outputs
- Daylighting Metrics
- Overview of Daylighting Tools
- Some Pretty Pictures
- Daylighting in SPOT, DAYSIM, and IES

Daylighting…what is it?

Table1: Five sample definitions for daylighting (Reinhart C F & Galasiu A, 2006).

Architectural definition: the interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment
Lighting Energy Savings definition: the replacement of indoor electric illumination needs by daylight, resulting in reduced annual energy consumption for lighting
Building Energy Consumption definition: the use of fenestration systems and responsive electric lighting controls to reduce overall building energy requirements (heating, cooling, lighting)
Load Management definition: dynamic control of fenestration and lighting to manage and control building peak electric demand and load shape
Cost definition: the use of daylighting strategies to minimize operating costs and maximize output, sales, or productivity

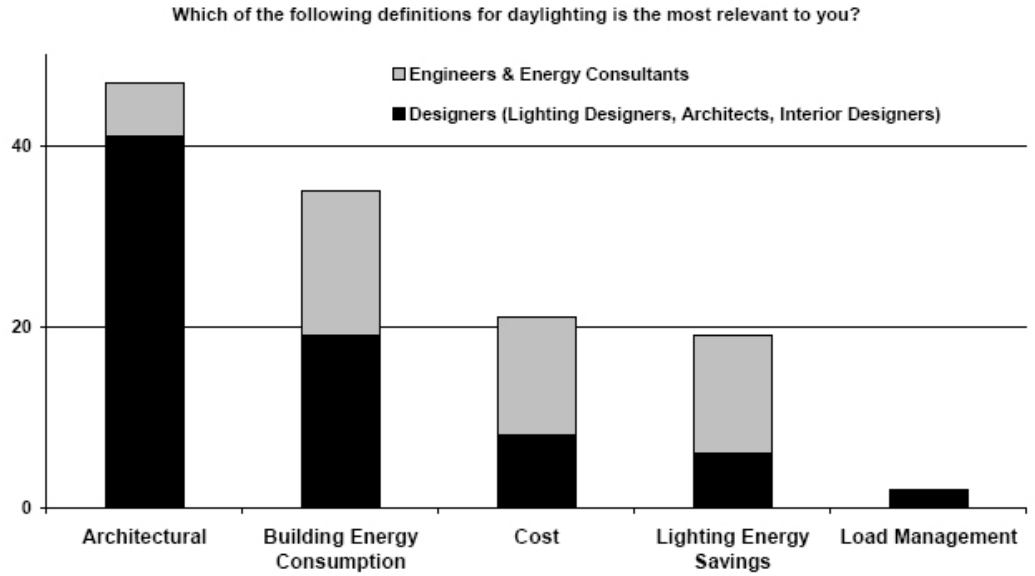
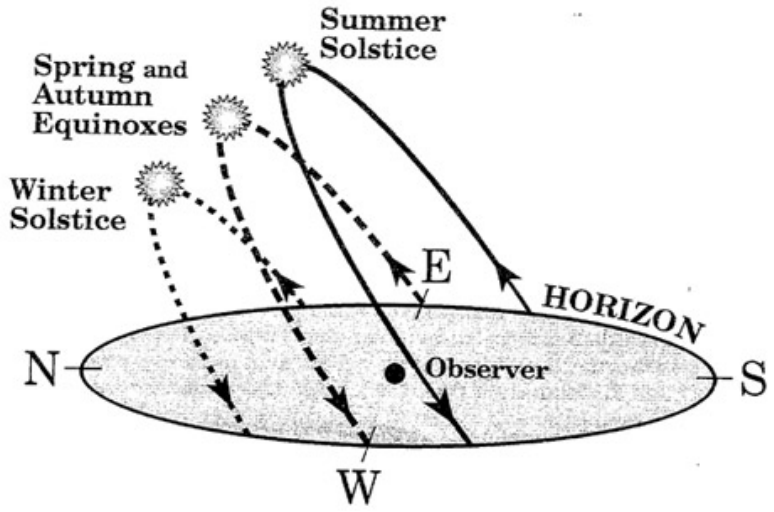


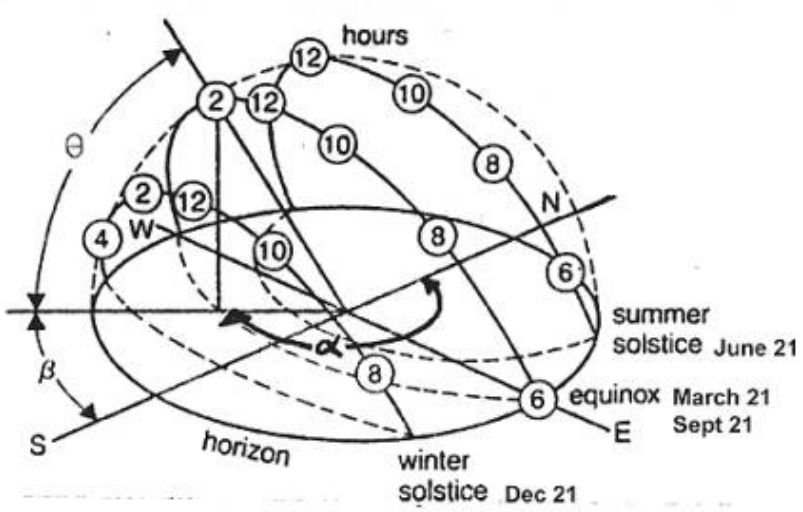
Figure 1: Results of a recent survey on the role of daylighting in sustainable design (Reinhart C F & Galasiu A, 2006).

Daylighting…why do we care?

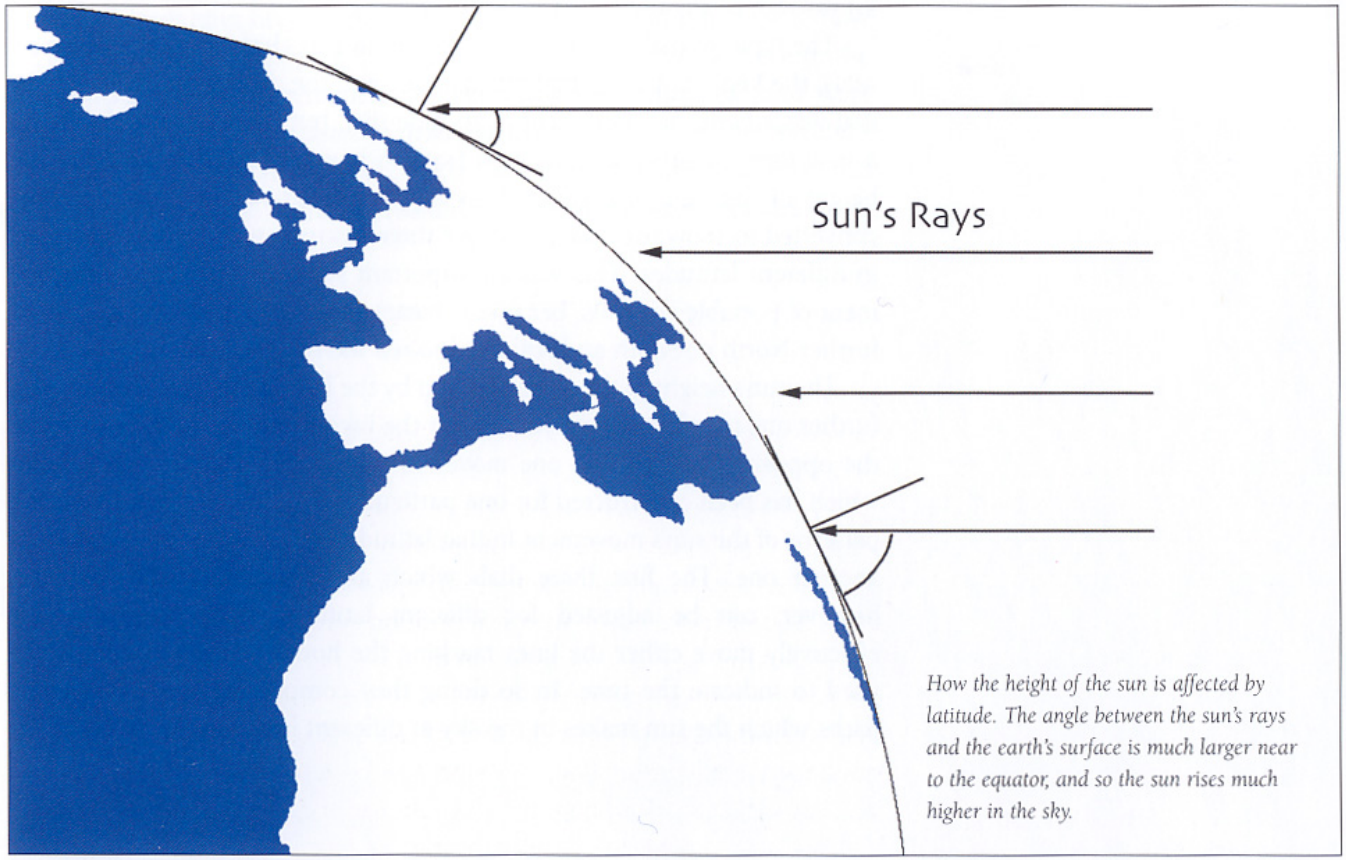
- Aesthetic value
- Health value
- Economic value
- Functional value
- Thermal value
- It's just plain cool

Solar Position



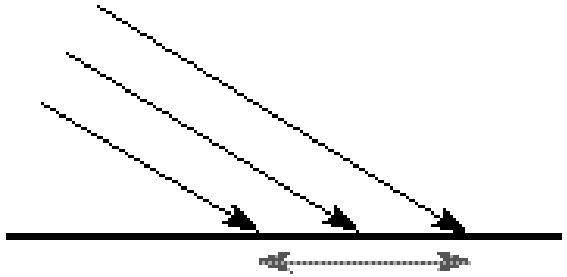


Variations in Incident Solar

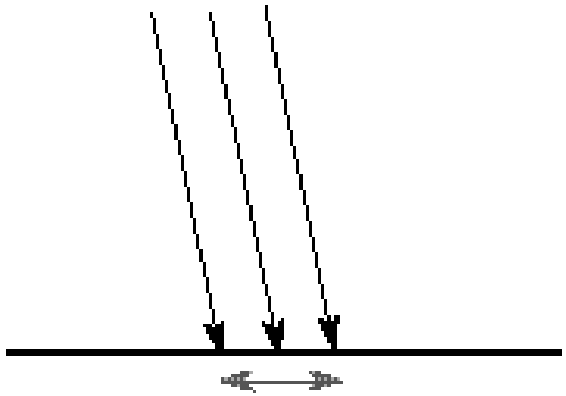


How the height of the sun is affected by latitude. The angle between the sun's rays and the earth's surface is much larger near to the equator, and so the sun rises much higher in the sky.

Seasonal Angles

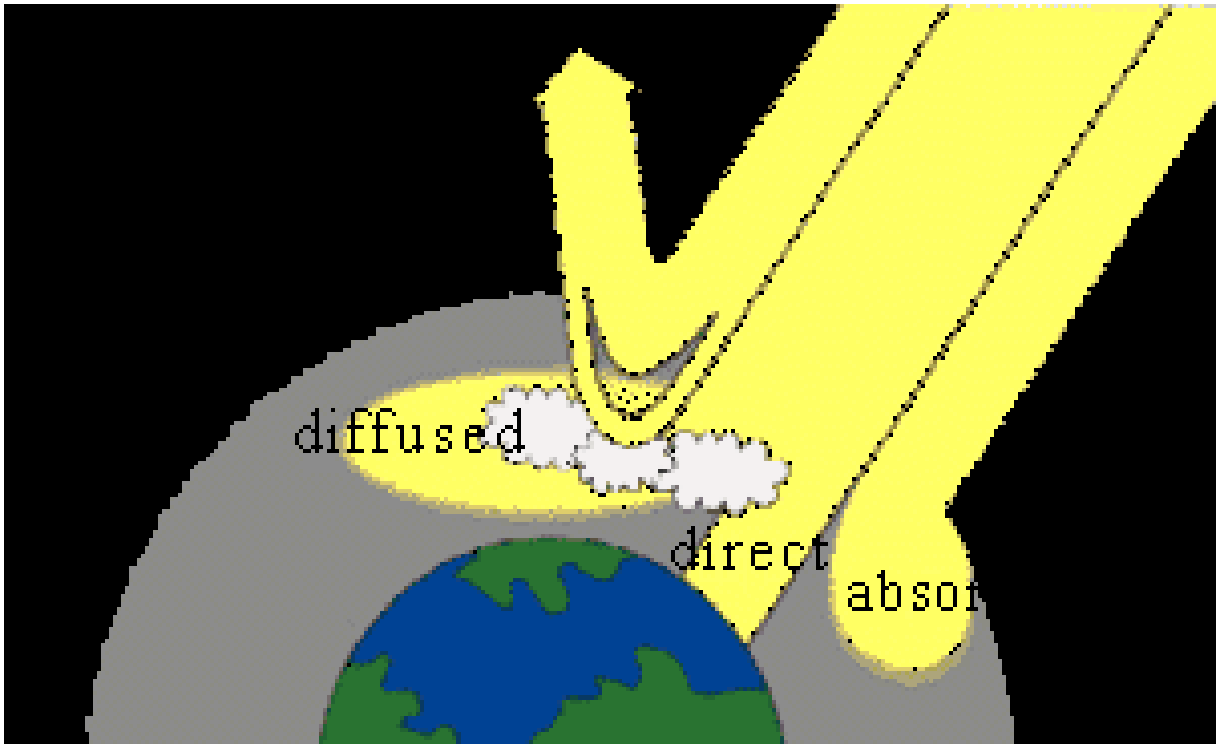


Same energy but more spread out, means less heating.



Same energy but more concentrated, means greater heating.

Diffuse and Direct Components



Diffuse Sky Conditions

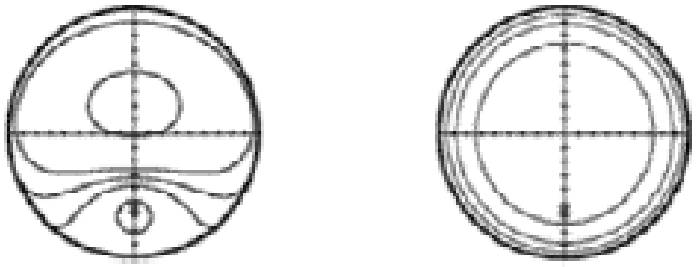
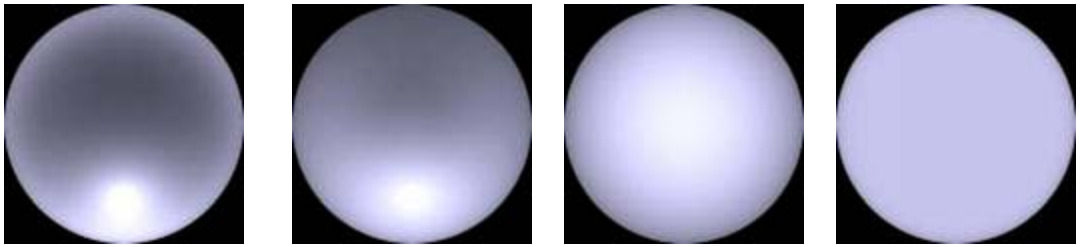


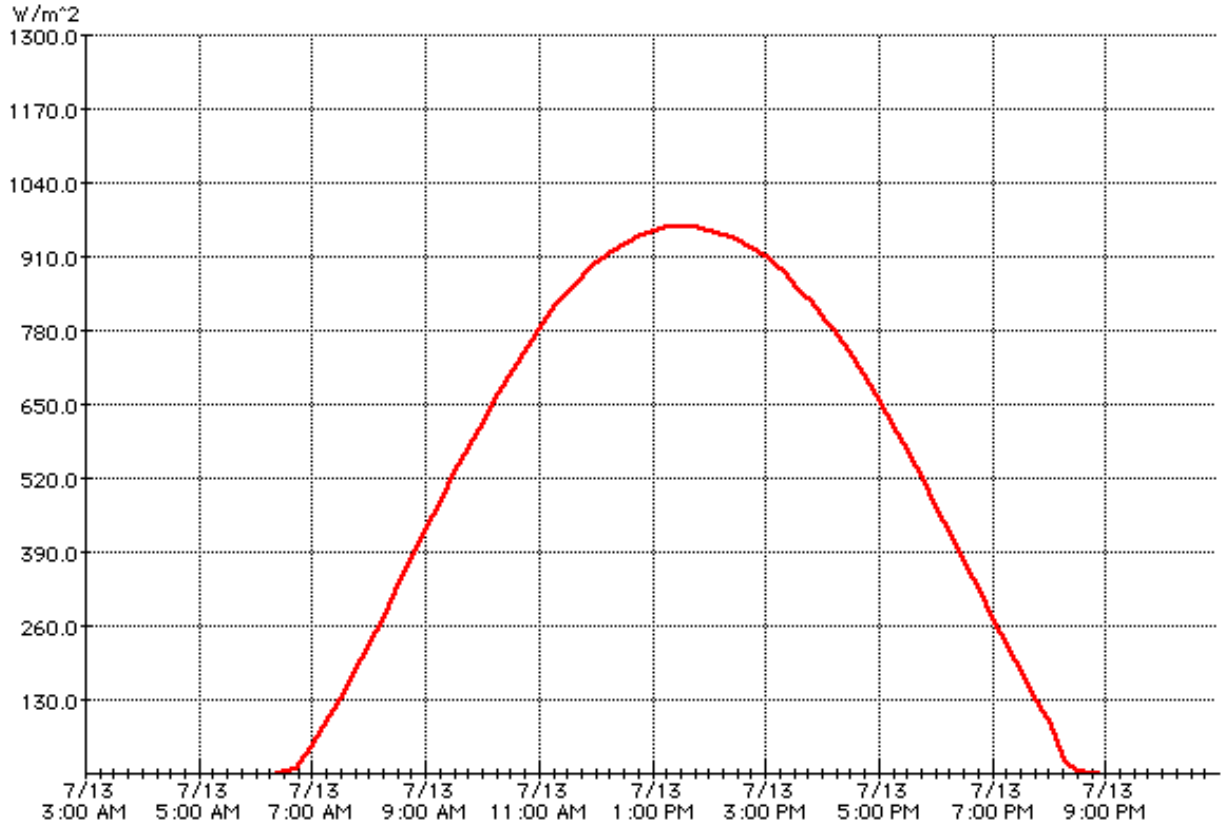
Fig. 1 CIE Sky Luminance Distribution Functions



Clear sky Intermediate sky Overcast sky Uniform sky

LIGHTING/DAYLIGHTING ANALYSIS: A COMPARISON
Harvey Bryan, Ph.D., FAIA
Sayyed Mohammed Autif
http://www.learn.londonmet.ac.uk/packages/clear/visual/daylight/sun_sky/sky_types.html

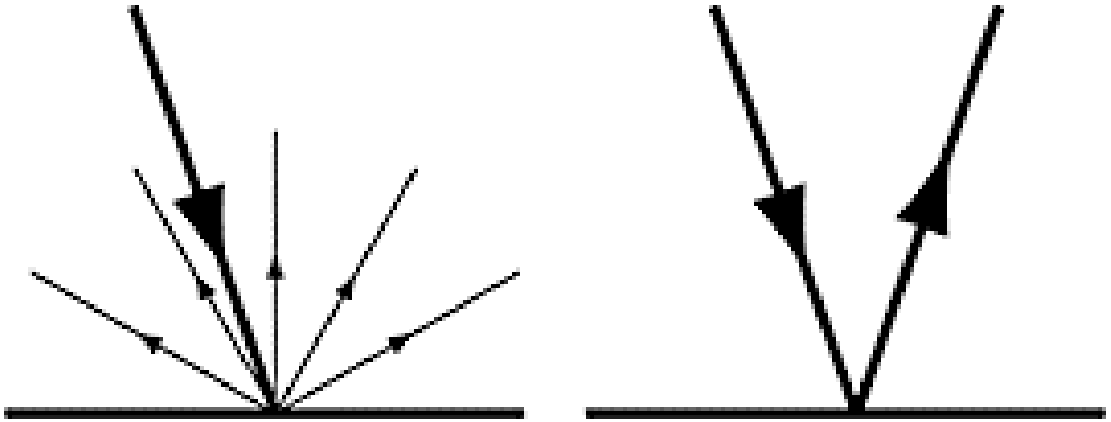
Daily Solar Radiation



Time
Start: 7/13/97 03:00 AM (CDT)
End: 7/13/97 11:00 PM (CDT)
Interval: 0:15

Plots
✓ Solar Radiation (W/m^2)
Spencer

Surface Properties

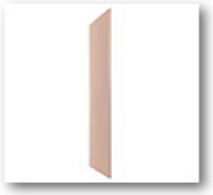


Diffuse Specular

Glazing Types

Window Technologies: Glazing Types

Single-glazed Clear



Single-glazed with Bronze/Gray Tint

Double-glazed Clear

Double-glazed with Bronze/Gray Tint

Double-glazed with High Performance Tint

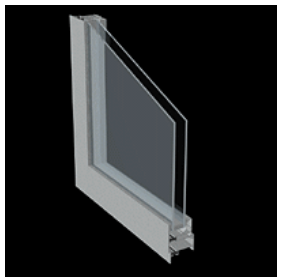
Double-glazed with High-Solar-Gain Low-E, Argon/Krypton Gas

Double-glazed with Moderate-Solar-Gain Low-E, Argon/Krypton Gas

Double-glazed with Low-Solar-Gain Low-E Argon/Krypton Gas

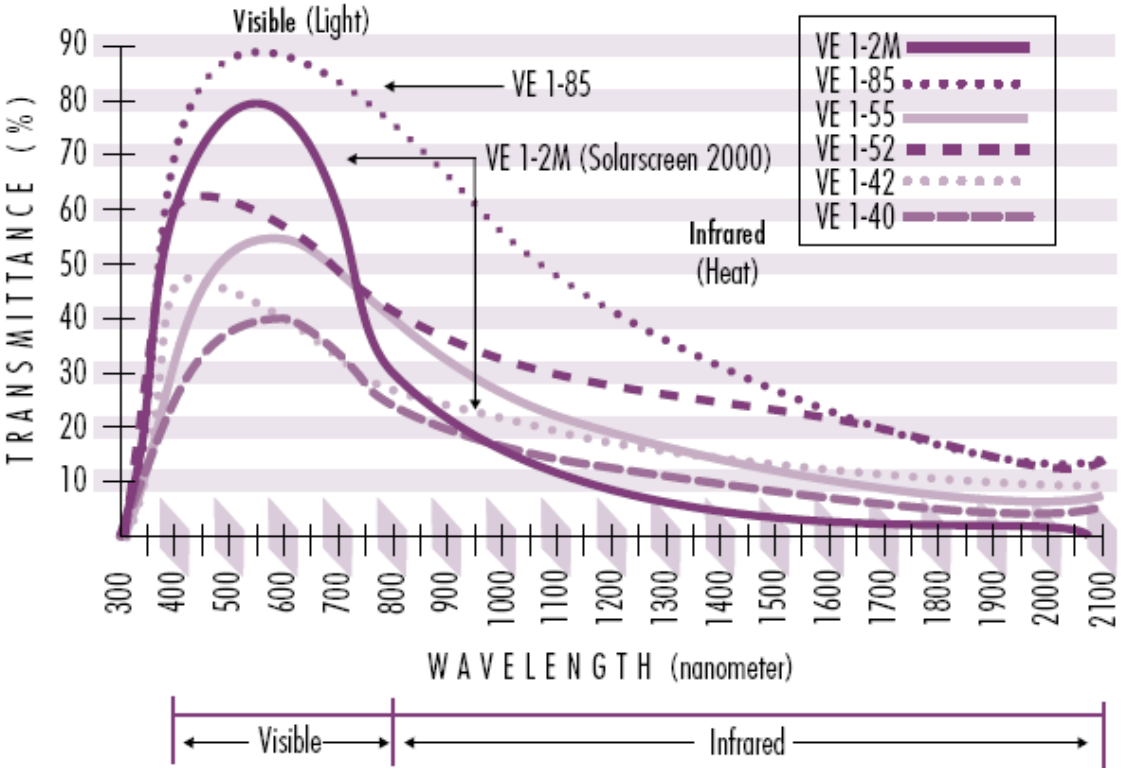
Triple-glazed with Moderate-Solar-Gain Low-E, Argon/Krypton Gas

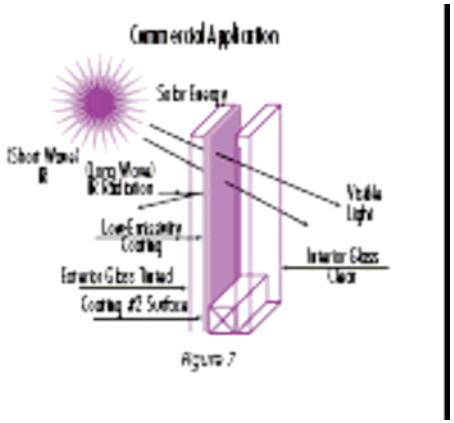
Triple-glazed with Low-Solar-Gain Low-E, Argon/Krypton Gas



http://www.efficientwindows.org/index.cfm

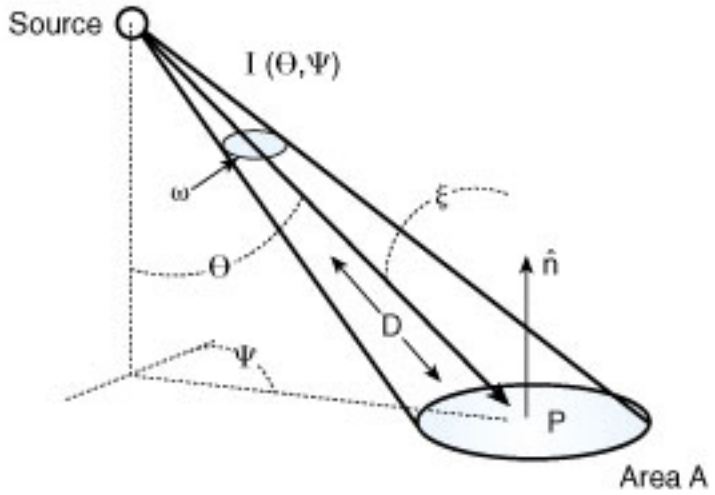
Spectrally Selective Glazing



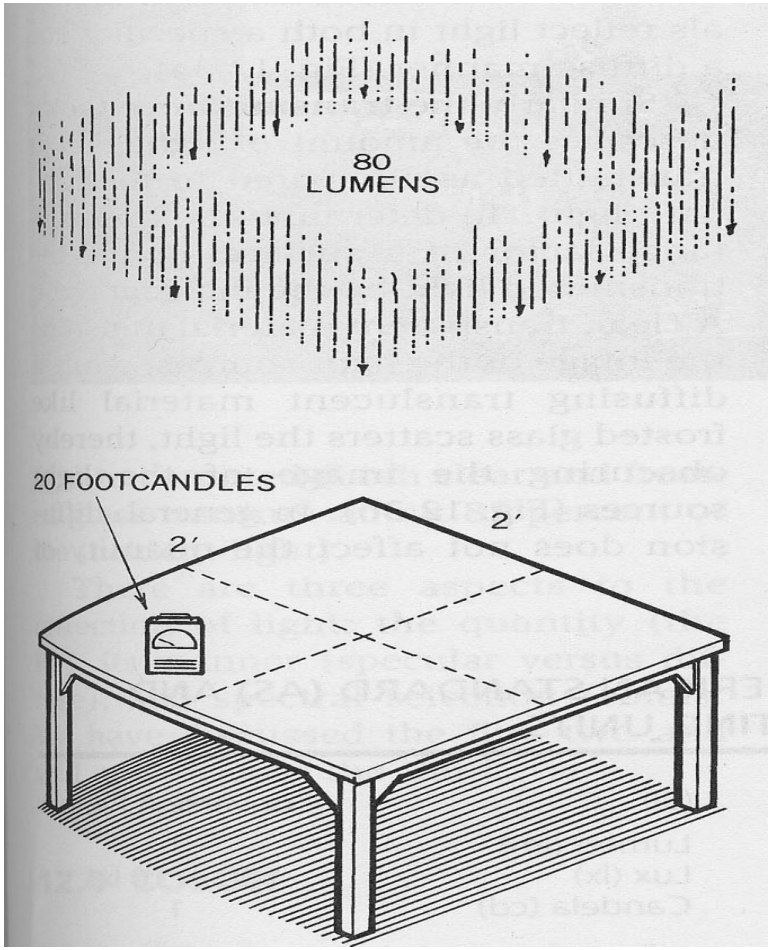


What is Illuminance?

- Amount of light striking a point on a surface. [units: footcandle, lux (luminous flux per unit area ex: lumen per SF)]



Illuminance (cont'd)

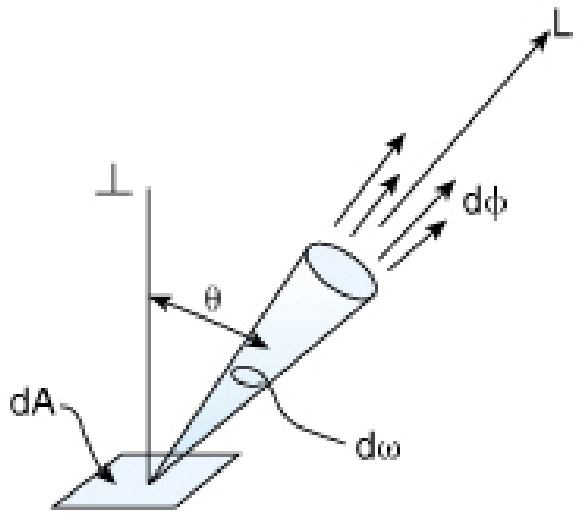


Illuminance = Lumens/ft^2

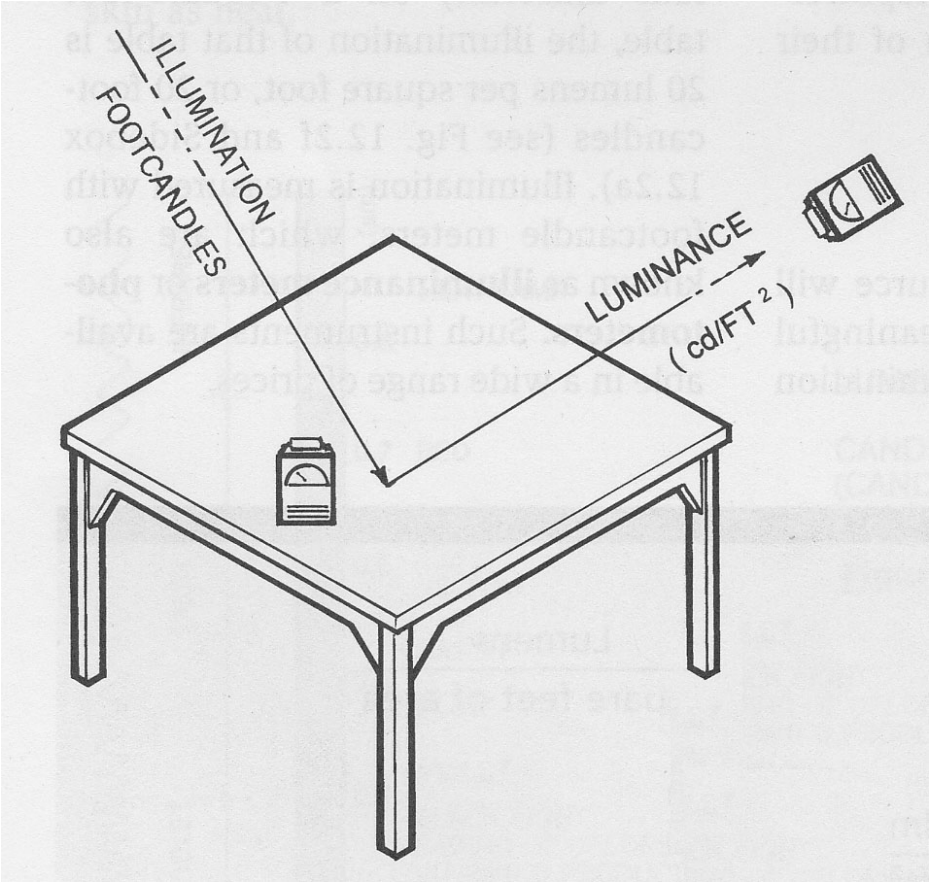
Illuminance: the number of lumens falling in each square foot of a surface.

What is Luminance?

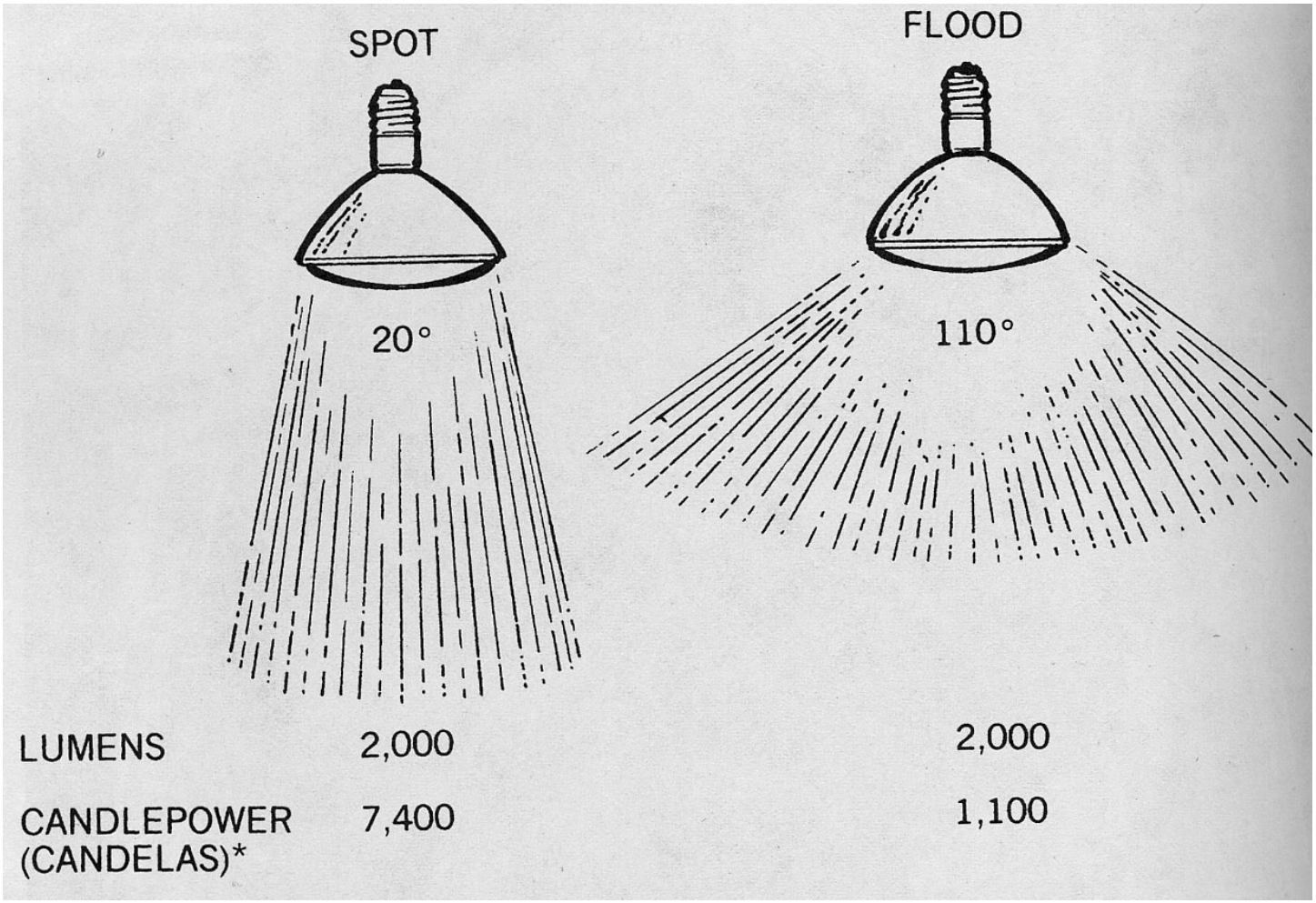
- **Luminance,** the amount of light reflected by a surface in a specific direction. [units: luminous intensity per area, ex. candelas/ SF]



Illuminance vs. Luminance



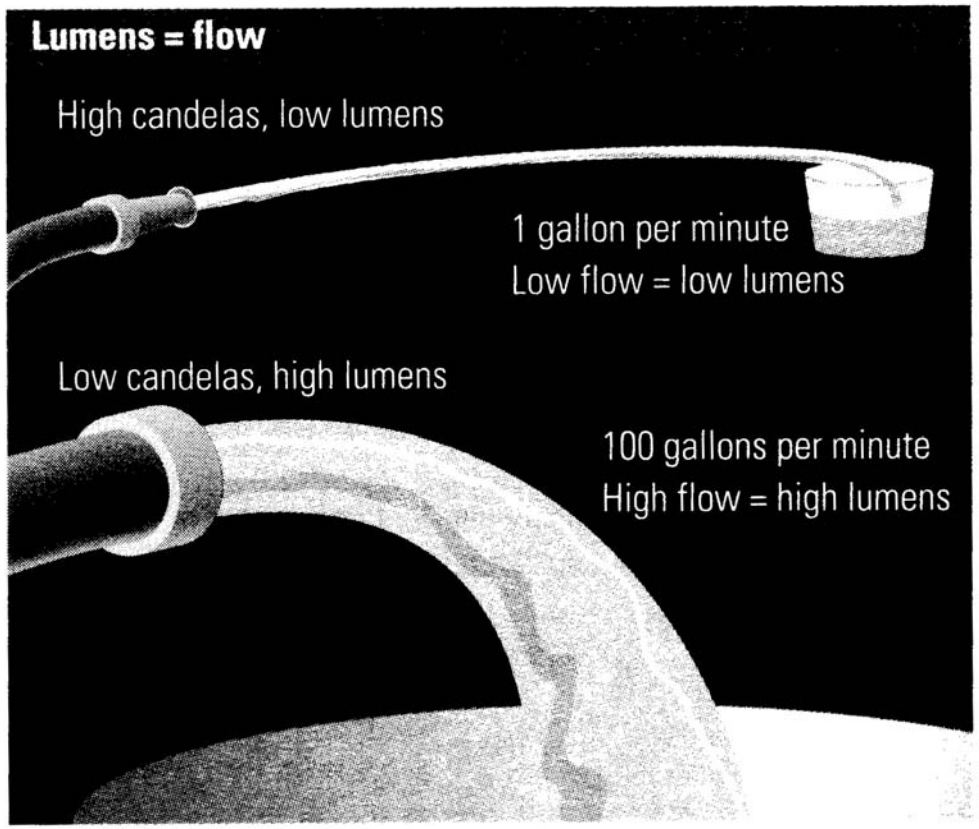
Light Output



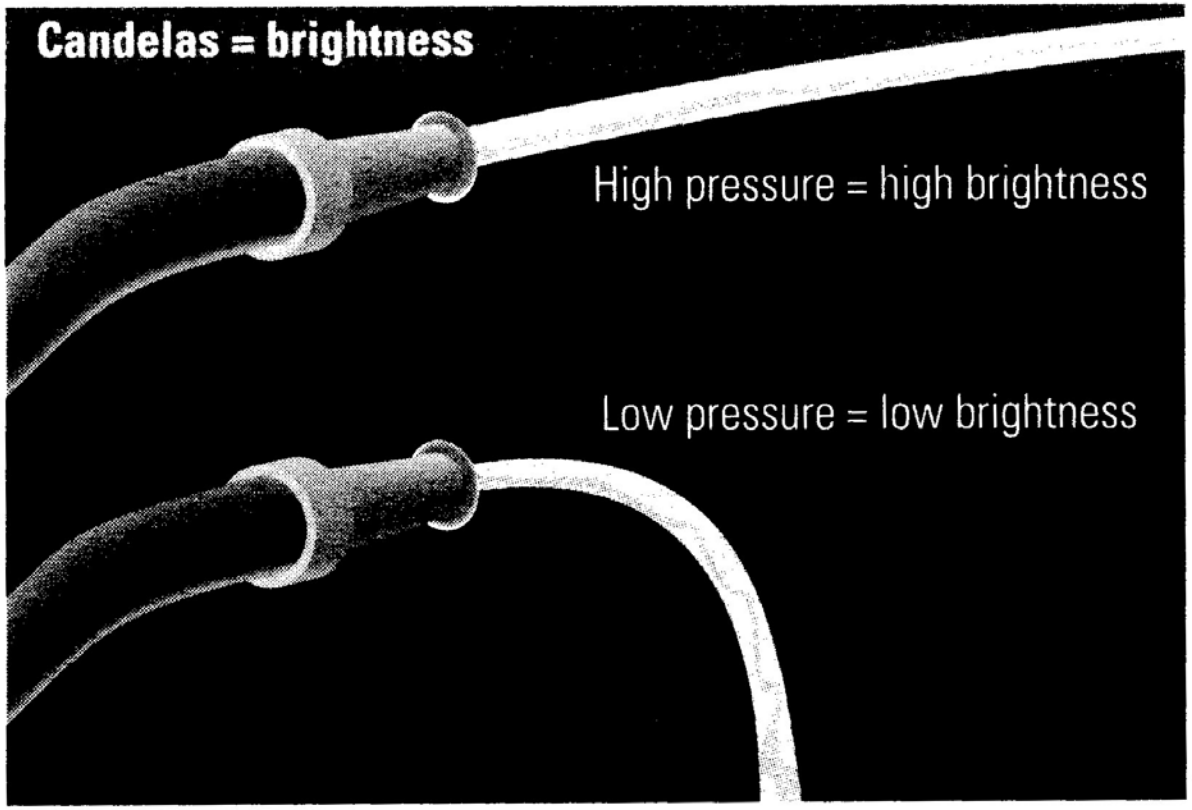
Luminous Flux

Luminous Intensity

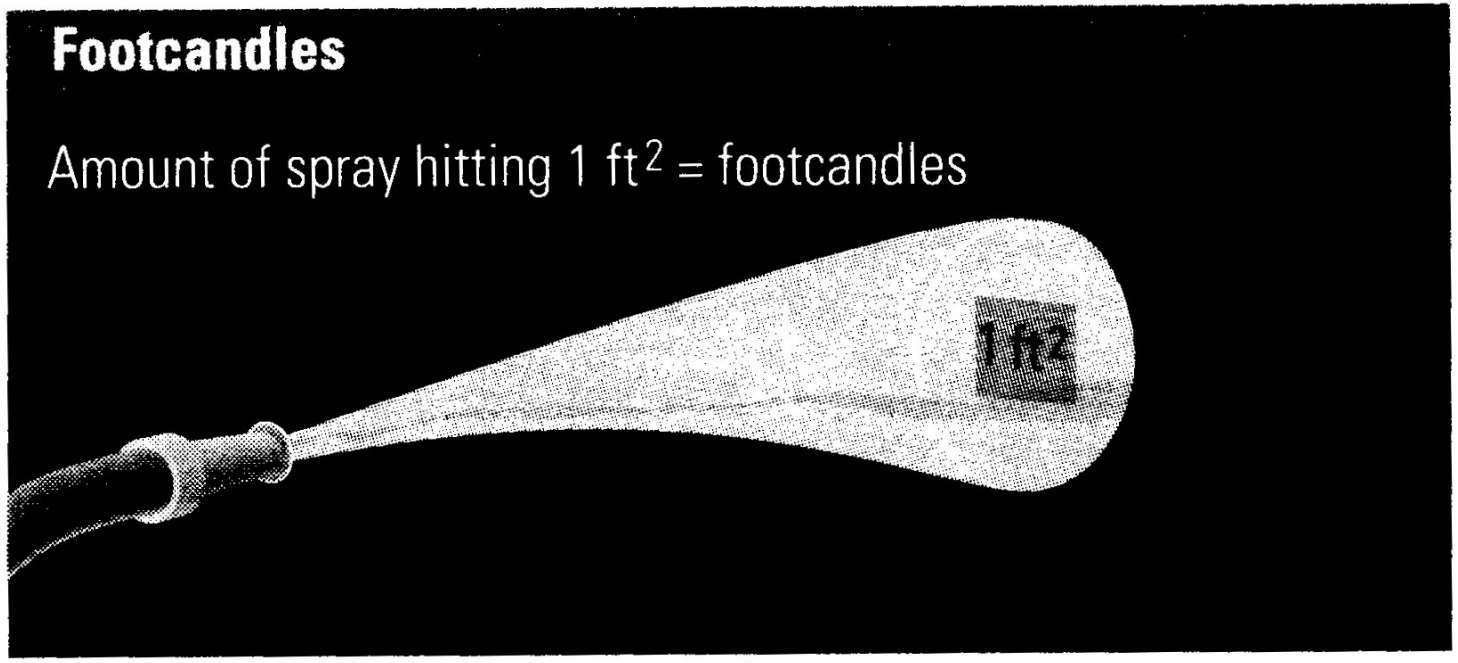
Lumens (Amount of Light)



Brightness (Intensity of Light)



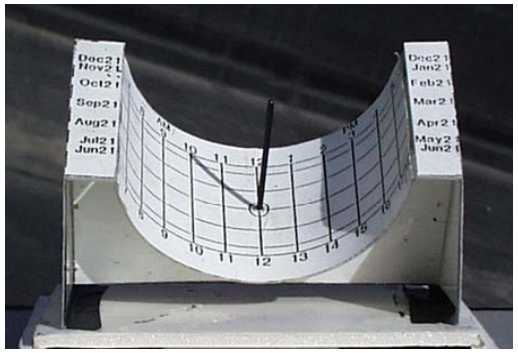
Illuminance (Light Arriving at a Surface)



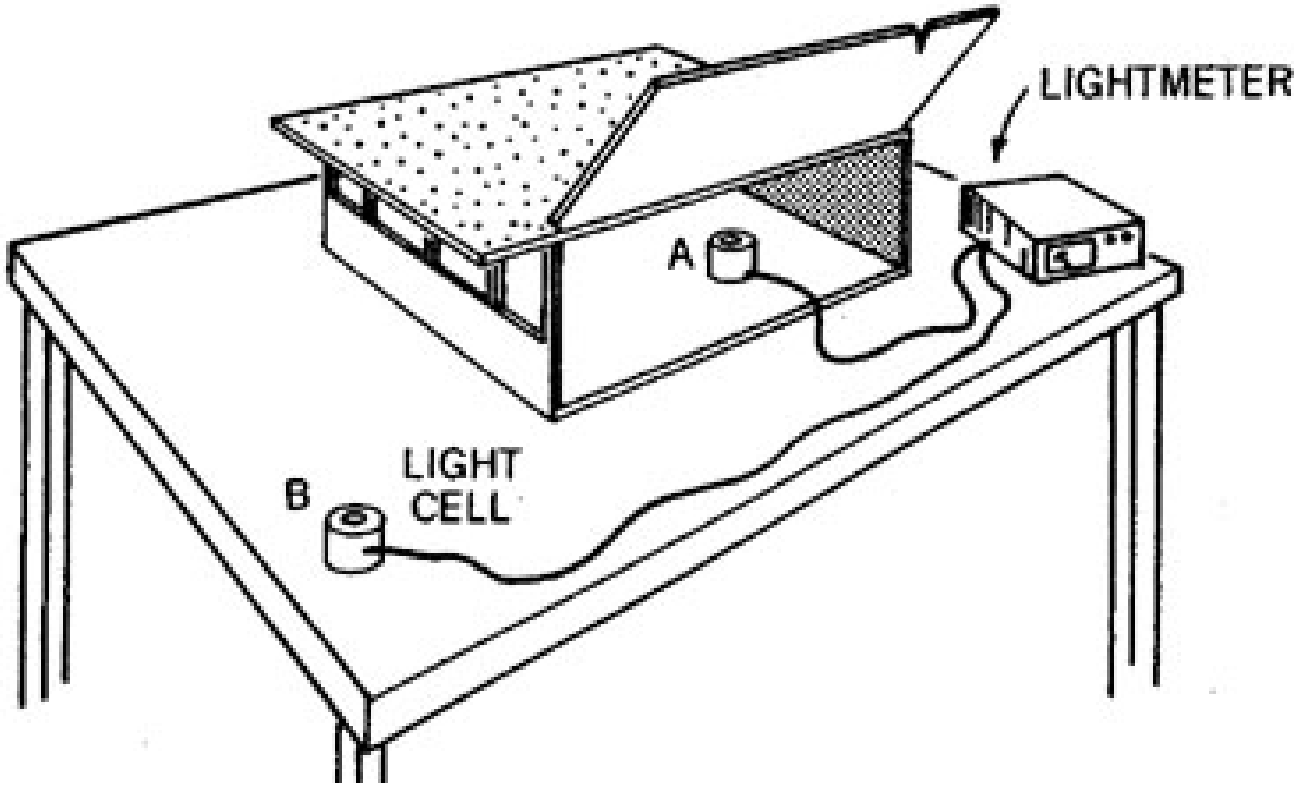
Lighting Units

Measure	Unit
Luminous Flux	Lumen
Illuminance	Footcandle = lumen / ft^2
Luminous Intensity	Candela
Luminance	Candela / unit area

Physical Daylighting Models



Illuminance Measurements



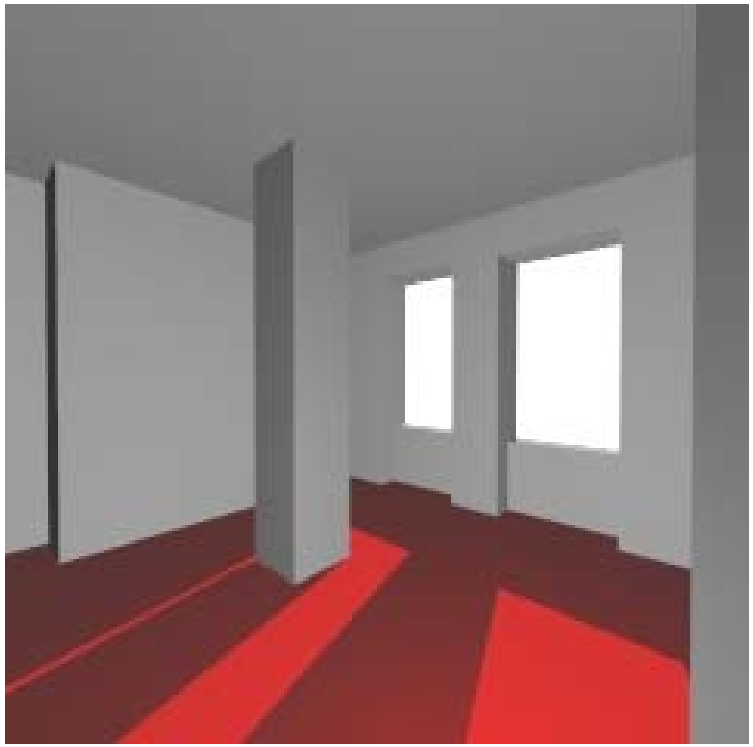
Advantages of using a computer…

- Easy Changes (modifiable).
- Internal or external obstructions can be handled easily.
- Material and glazing properties.
- Controlled weather conditions.

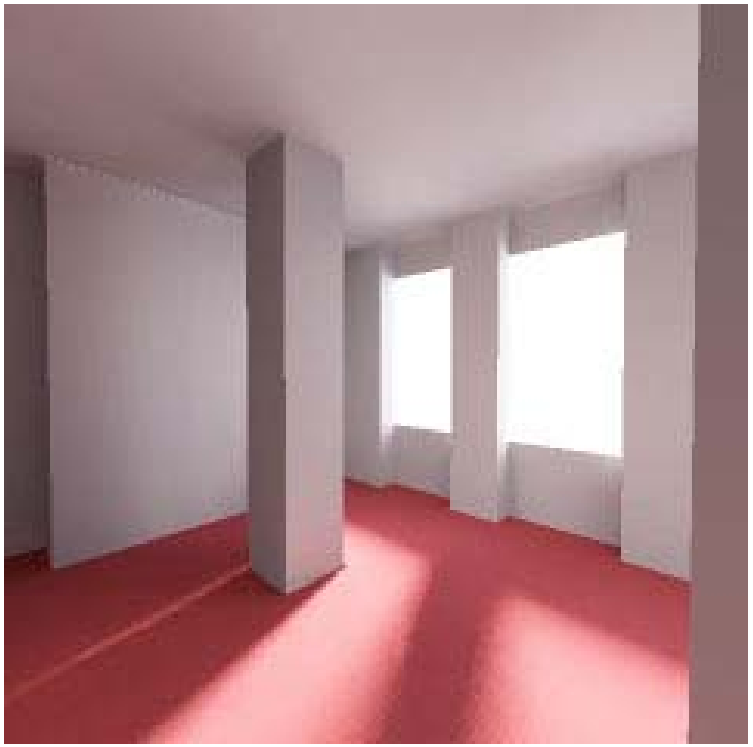
Basic Daylight Model Inputs

- Solar resource (location, date, weather)
- Geometry (interior and exterior)
- Building orientation
- Surface properties (reflectances, specularity)
- Glazing properties
- Solar control strategies

Radiosity vs. Ray Tracing



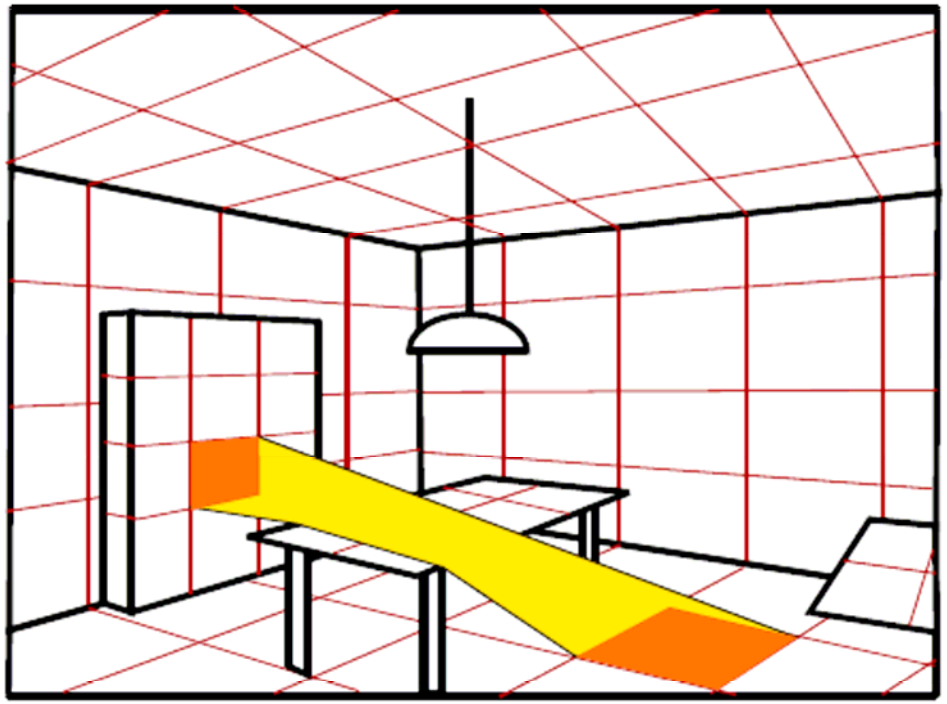
Radiosity



Backward Ray Tracing

Radiosity

- Diffuse surfaces
- Subdivide scene
- Radiosity assumed constant over a patch
- Form-factor between patches
- Geometry and visibility
- Big Matrix system



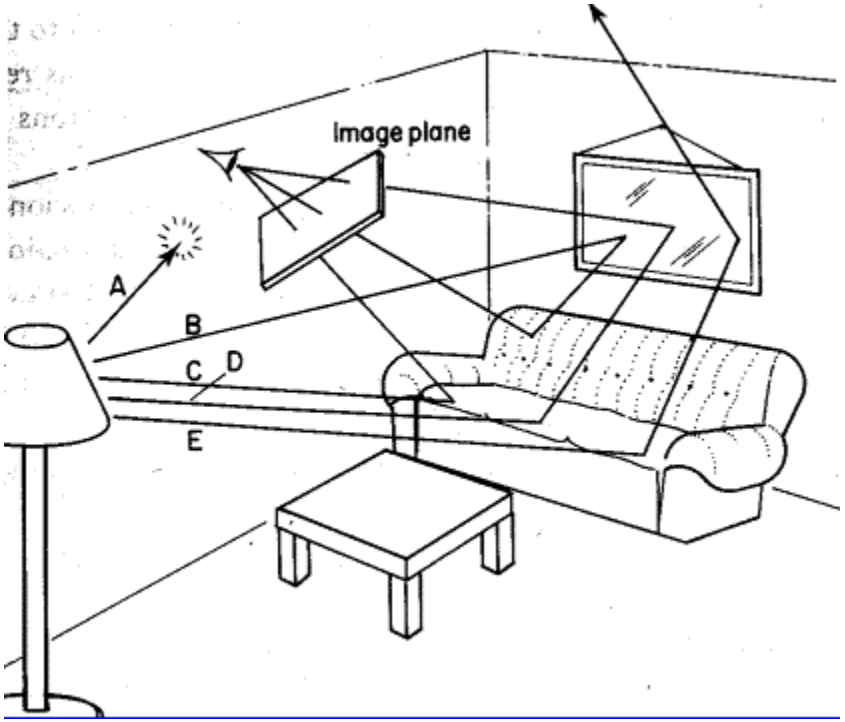
MIT EECS 6.837, Cutler and Durand

Limitations of radiosity

- Diffuse only for basic method
  - Costly extension to specular
- Requires meshing
- Cost of visibility computation
  - If you send rays, why not use ray tracing?
- Memory consumption vs. time scalability

Ray Tracing

- Handles specular reflections very well
- Best for rendering applications

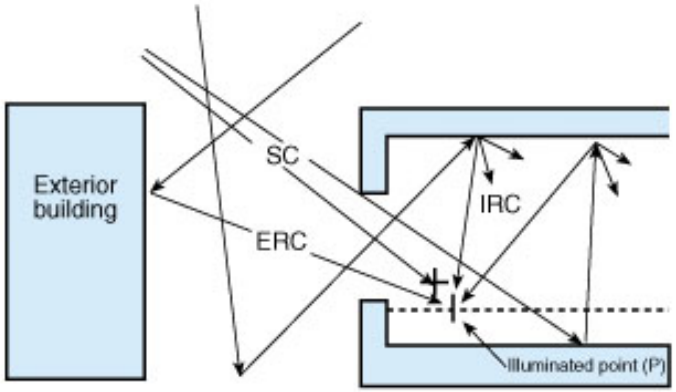


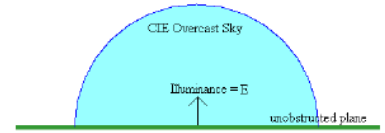
Summary of Modeling Outputs

- Illuminance levels
- Illuminance distribution
- Luminance ratios
- Glare probability
- Direct light penetration
- Performance metrics

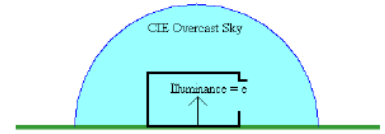
Daylighting Metrics- Daylight Factor (static)

- Ratio of the illuminance on the given plane at that point to the simultaneous exterior illuminance on a horizontal plane from the whole of an unobstructed sky.
- Daylight Factor (DF) = Sky + Reflected External + Reflected Internal
- Assumes an overcast sky for worse case conditions
- Most commonly used metric in daylighting design
- It is a poor metric for it does not take into account orientation, clear-sky days, and operating schedule





E = illuminance on unobstructed plane



e = illuminance at point in interior

Daylight Factor = **e/E** (often expressed as a percentage)

Illuminance is measured in **LUX**

Daylighting Metrics- Daylight Factor (dynamic)

- **Daylight Autonomy (DA):** the percentage of the year when a minimum illuminance threshold is met by daylight alone.

- **Useful Daylight Illuminances (UDI):** UDI results in three metrics: the percentages of the occupied times of the year when the UDI was achieved (100-2000lux), fell-short (<100 lux), or was exceeded (> 2000 lux).

- **Continuous Daylight Autonomy (DAcon):** like DA, but partial credit is attributed to time steps when the daylight illuminance lies below the minimum illuminance level. For example, in the case where 500 lux are required and 400 lux are provided by daylight at a given time step, a partial credit of 400lux/500lux=0.8 is given for that time step.

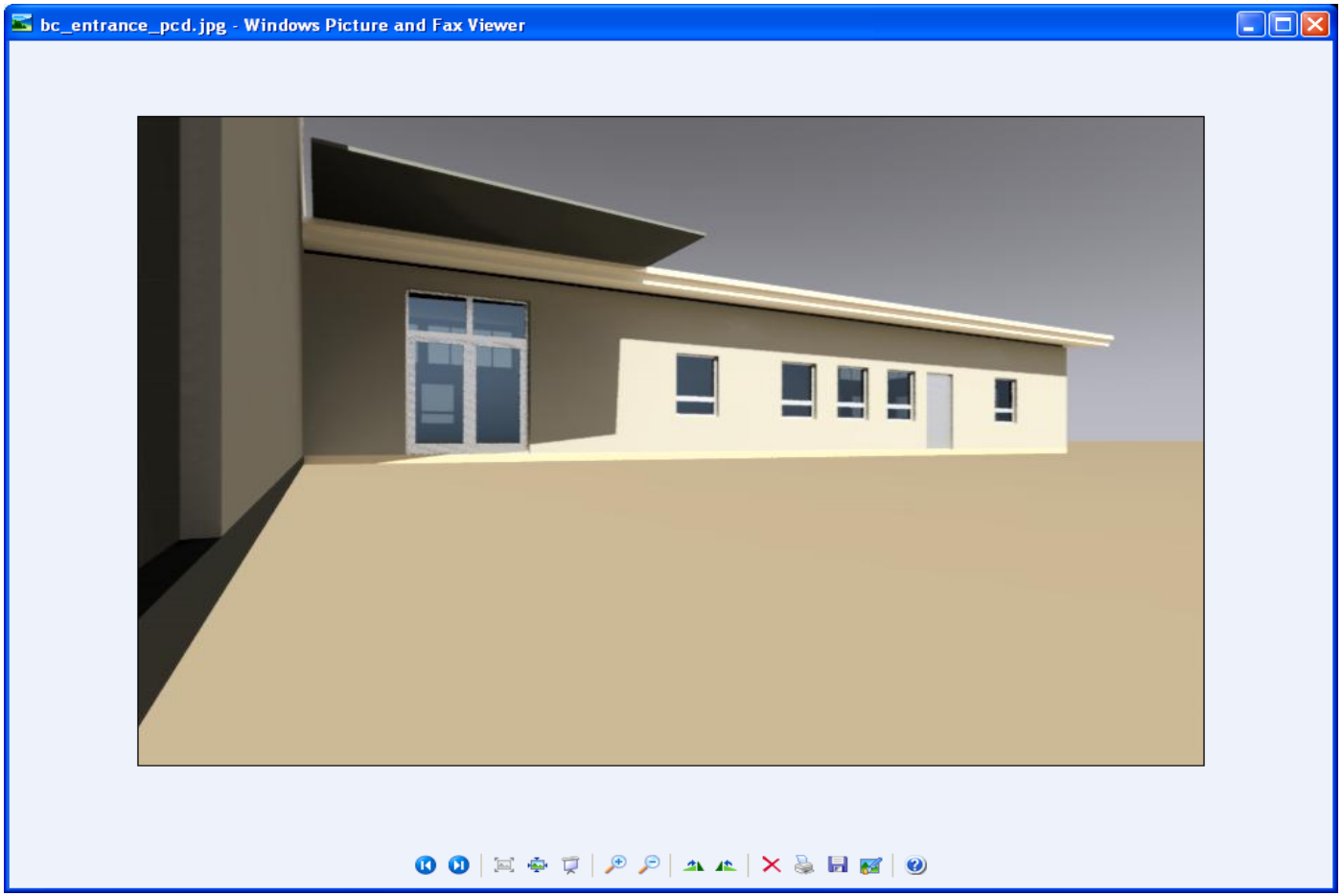
Dynamic metrics are more useful for daylighting design for they account for operating schedule, varying sky conditions, and orientation

Daylighting Simulation Software

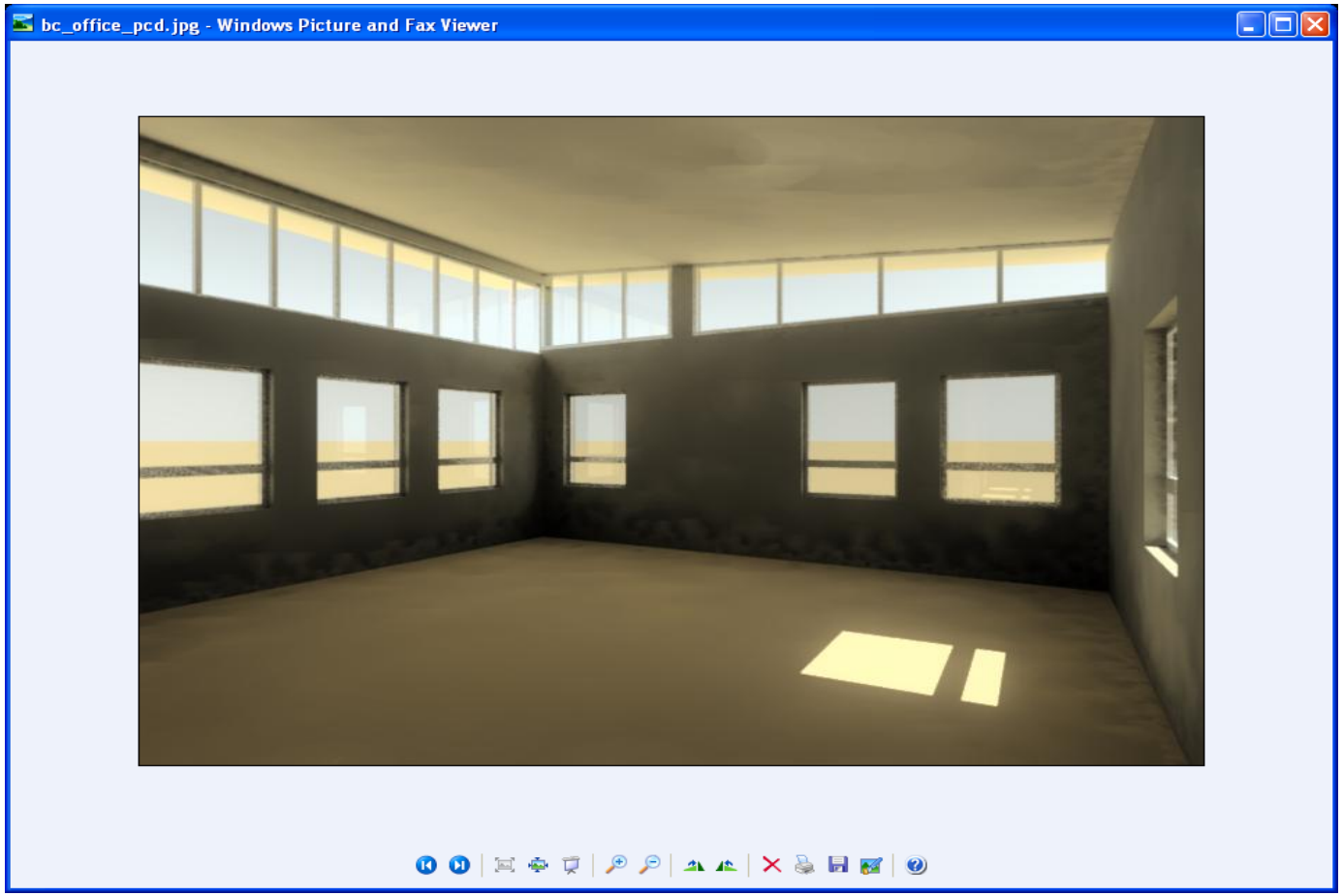
Software	Information	Cost	Comments
SPOT	http://www.archenergy.com/SPOT	Free	GUI to Radiance, Excel based, easy to use, dynamic
SkyCalc	http://www.energydesignresources.com/tools/skyclac.html	Free	Excel based, used for skylights
SuperLite	http://eetd.lbl.gov/btp/superlite20.html	Free	Radiosity, not used much
Trace-Pro	http://www.lambdares.com/	$12,000	Good integration with CAD and CATIA but $$$$$
Lumen Micro	http://www.lighting-technologies.com/	$595	Radiosity, popular
ECOTECT	http://www.squ1.com/	$90 Student License	DF calcs only, limited capabilities, exports to DAYSIM and Radiance
Radiance	http://radsite.lbl.gov/deskrad/	Free	Widely used simulation engine, no GUI, has both ray tracing and radiosity
Desktop Radiance	http://radsite.lbl.gov/deskrad/	Free	Not really functional at this time, old
Rayfront	http://www.schorsch.com/rayfront/	$895	Website has been down all year
AGi32	http://www.agi32.com/	Free for us!	Radiosity, limited ray-tracing, very popular
DAYSIM	http://irc.nrc-cnrc.gc.ca/ie/lighting/daylight/daysim_e.html	Free	GUI to Radiance, good metrics, easy to use, dynamic

The pretty pictures you are all waiting for….

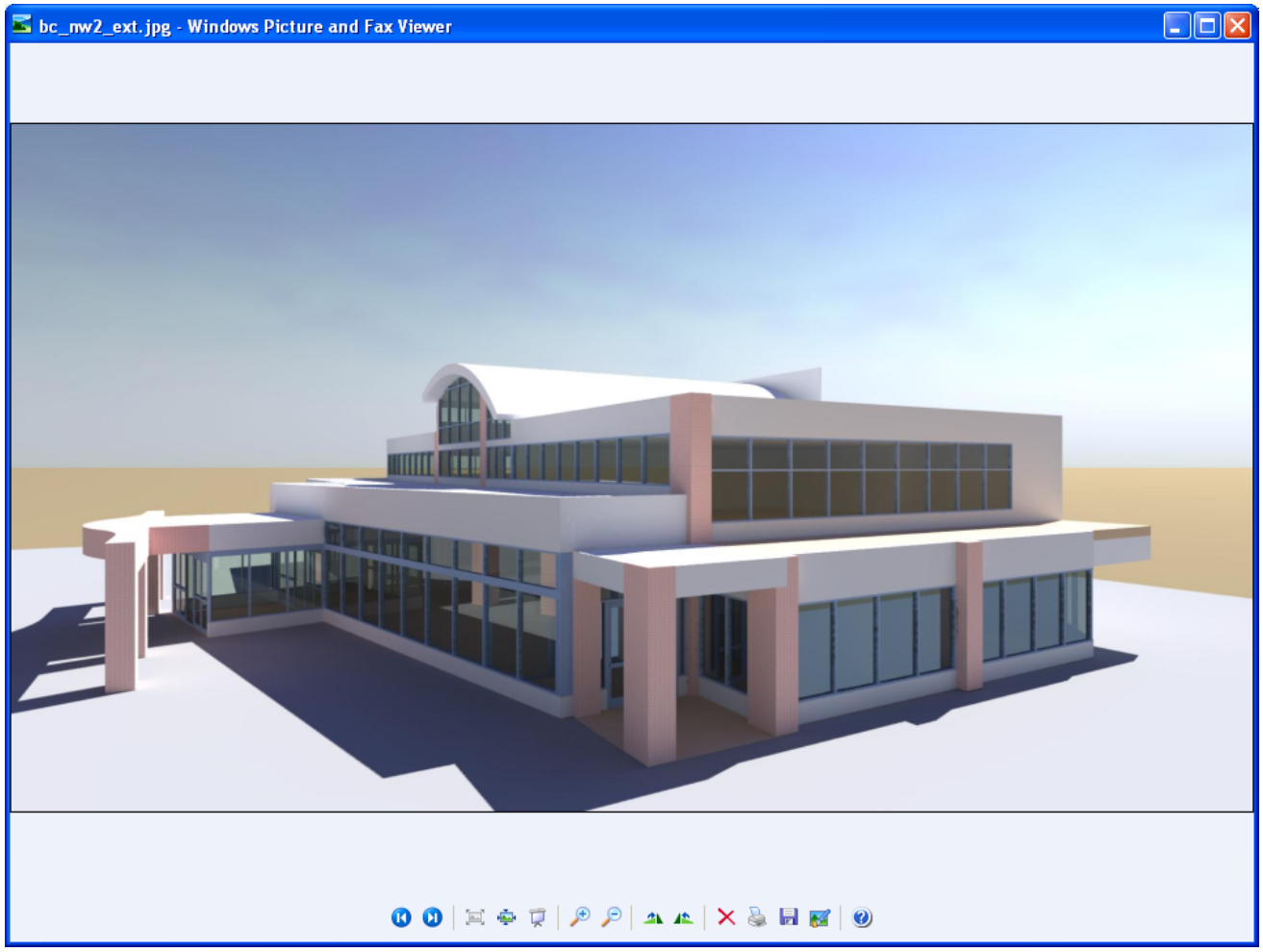
Radiance Modeling



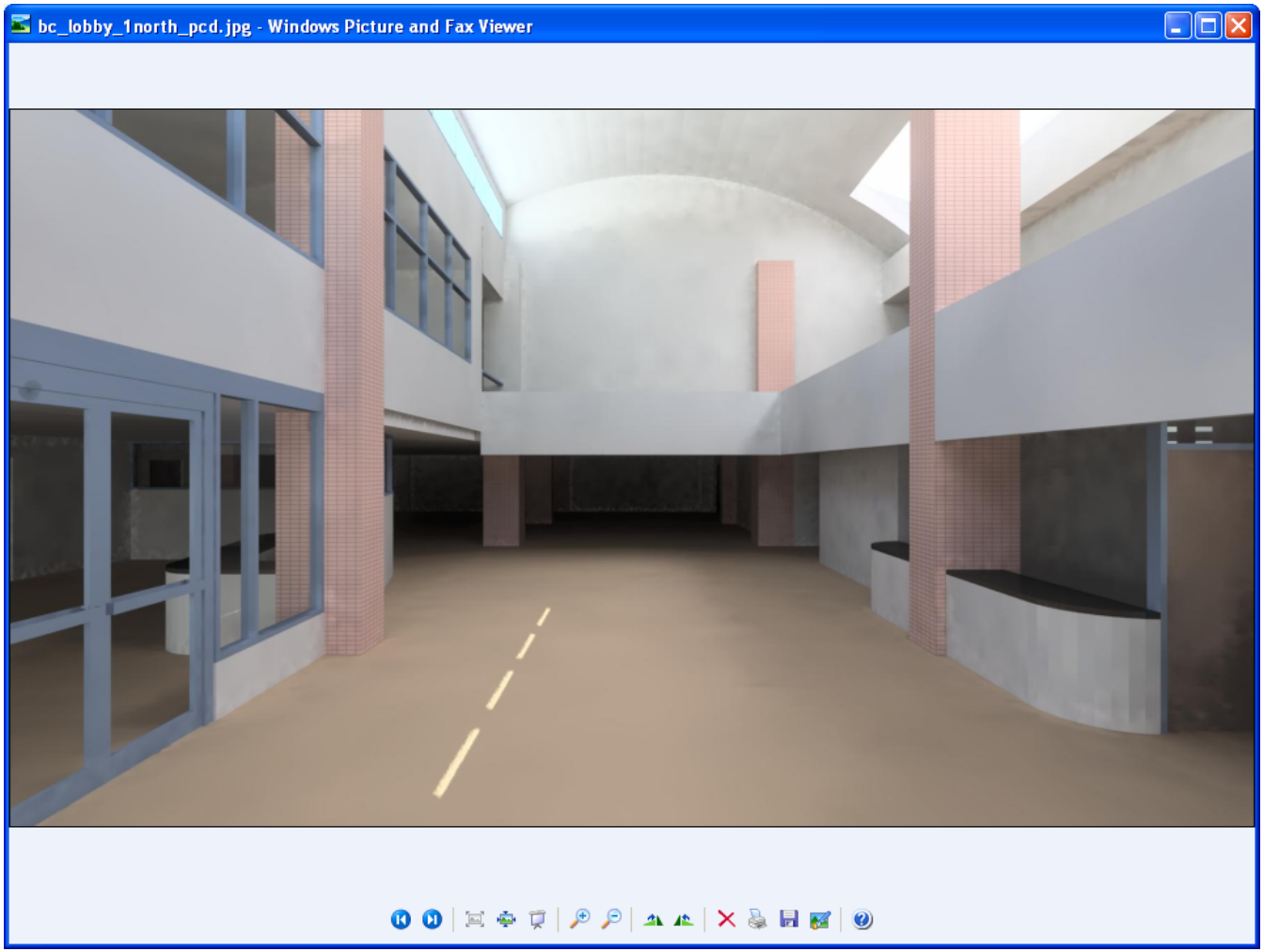
Radiance Modeling



Radiance Modeling

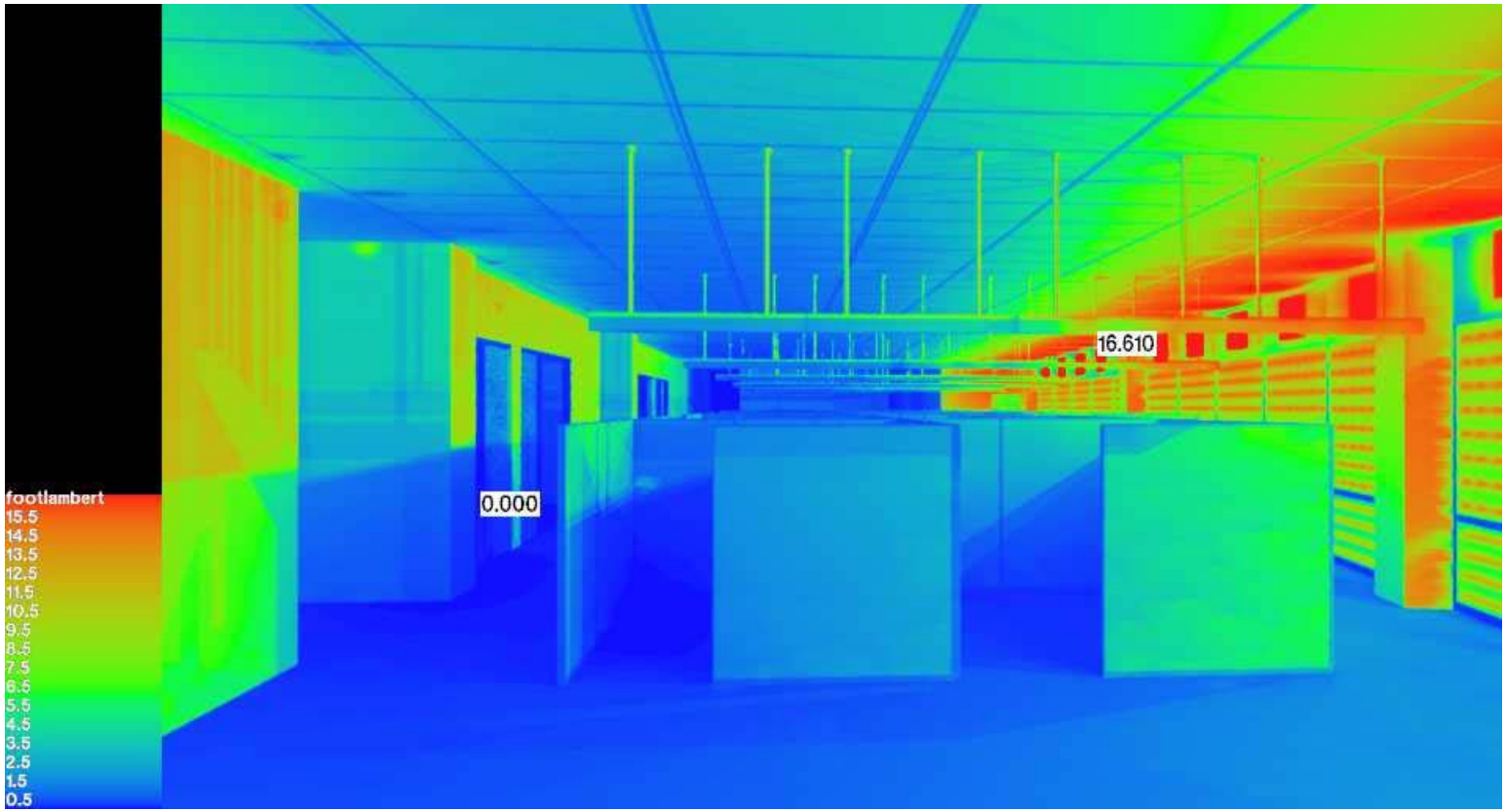


Radiance Modeling



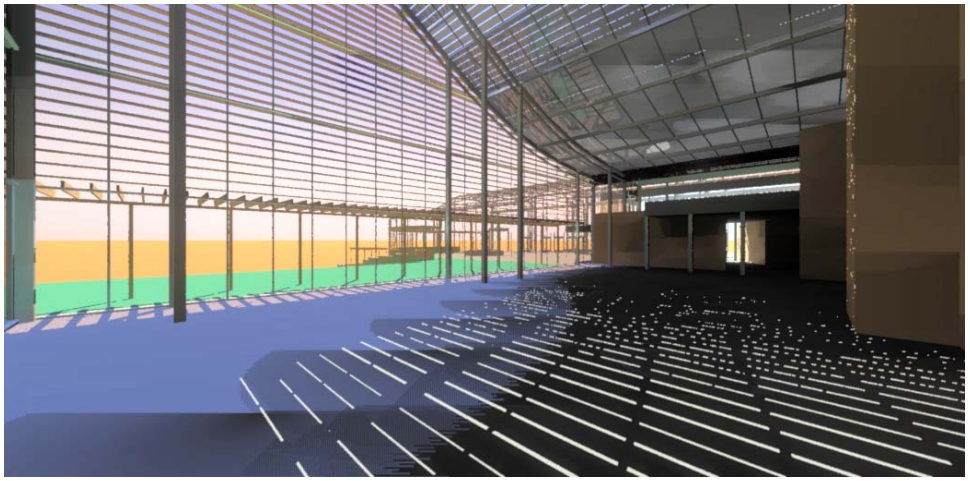
Radiance Modeling

Radiance Simulation



False Color Luminance Plot

Interior Luminous Environment

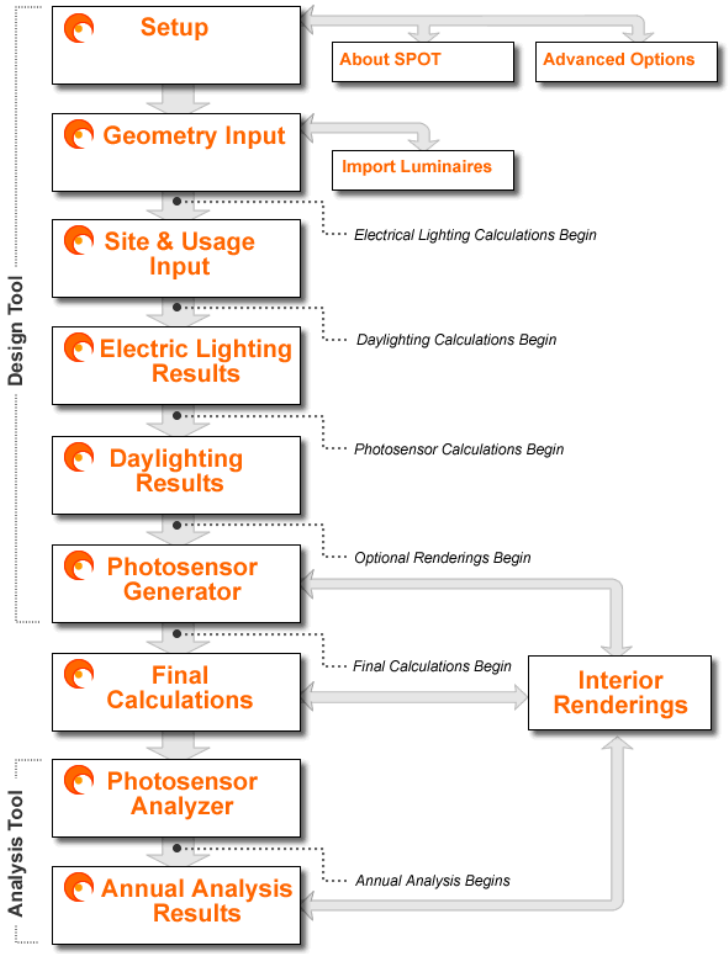


SPOT

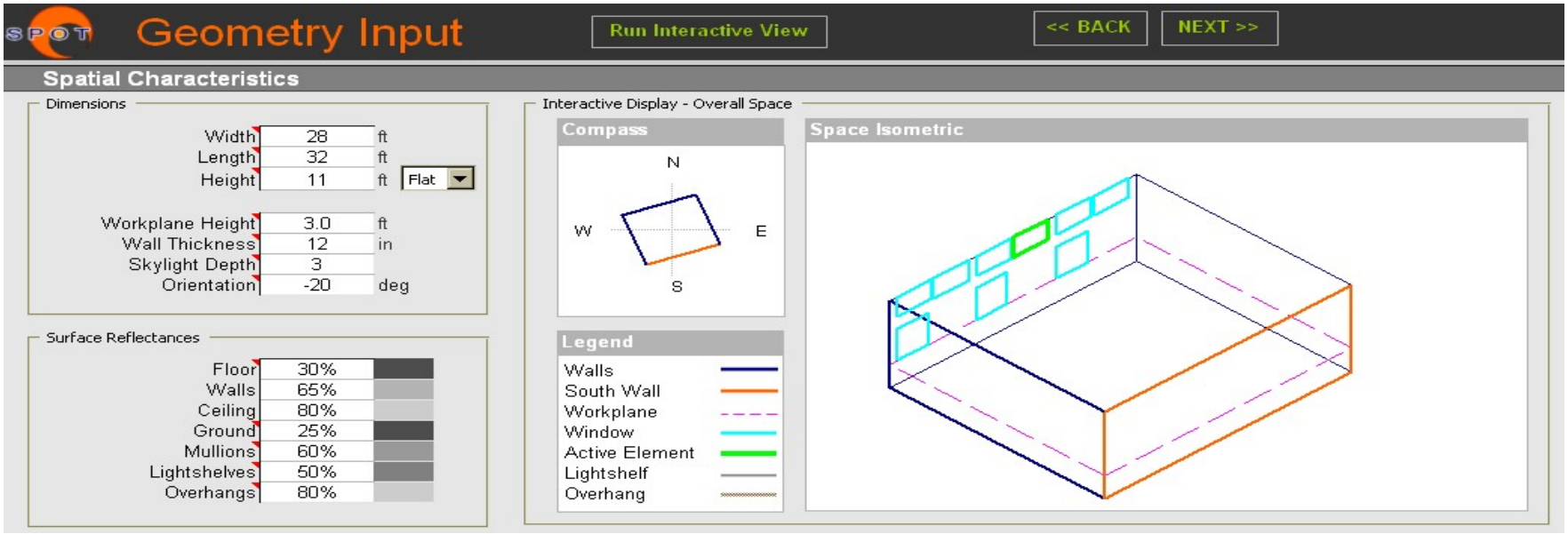
Sensor Placement + Optimization Tool

- Electric Lighting Analysis
- Annual Daylighting Analysis
- Photosensor Placement Optimization
- Photosensor System Optimization
- Annual System Performance Analysis

SPOT Modeling Process



SPOT- Geometric Input



SPOT- Daylighting Results

Daylighting Results

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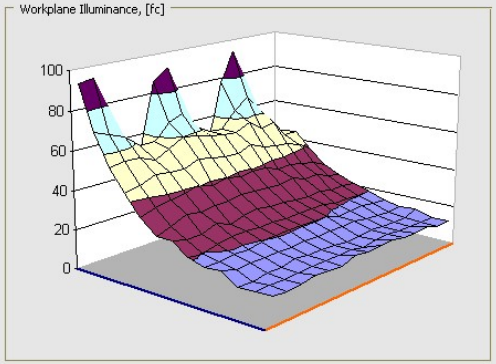
Annual Daylight Workplane Illuminance, [fc]

			Zone 1			Zone 2		
			Avg	Max	Min	Avg	Max	Min
	Clear Sky							
○	Winter	8:00AM	5	7	3	10	19	5
○		12:00PM	11	15	8	25	46	12
○		4:00PM	6	8	4	13	23	8
○	Equinox	8:00AM	9	13	6	21	40	12
○		12:00PM	16	25	11	46	76	22
○		4:00PM	13	20	9	37	66	20
○	Summer	8:00AM	14	23	10	41	70	21
○		12:00PM	22	36	15	70	114	33
○		4:00PM	26	42	16	87	167	42
	Overcast Sky							
○	Winter	8:00AM	4	6	2	11	23	6
○		12:00PM	17	27	11	47	99	24
○		4:00PM	5	8	3	15	30	7
○	Equinox	8:00AM	12	19	8	34	70	17
○		12:00PM	27	44	17	76	158	39
○		4:00PM	15	25	10	43	90	22
○	Summer	8:00AM	20	32	13	56	117	29
○		12:00PM	33	54	21	93	195	47
○		4:00PM	22	36	14	62	129	31
◉	Annual Average		18			49		
○	Annual Maximum			112			402	
○	DAF #1		0.11	0.37	0.01	0.71	0.90	0.32
○	DAF #2		0.56	0.76	0.43	0.87	0.93	0.74
○	DAFMax #1		0.00		0.00	0.00	0.00	0.00
○	DAFMax #2		0.06	0.09	0.04	0.16	0.31	0.09
○	DAF Wint		0.54	0.74	0.41	0.85	0.92	0.72
○	DAFMax Wint		0.00		0.00	0.00	0.00	0.00
○	DAF Sum		0.65	0.86	0.50	0.95	0.97	0.85
○	DAFMax Sum		0.00		0.00	0.00		0.00

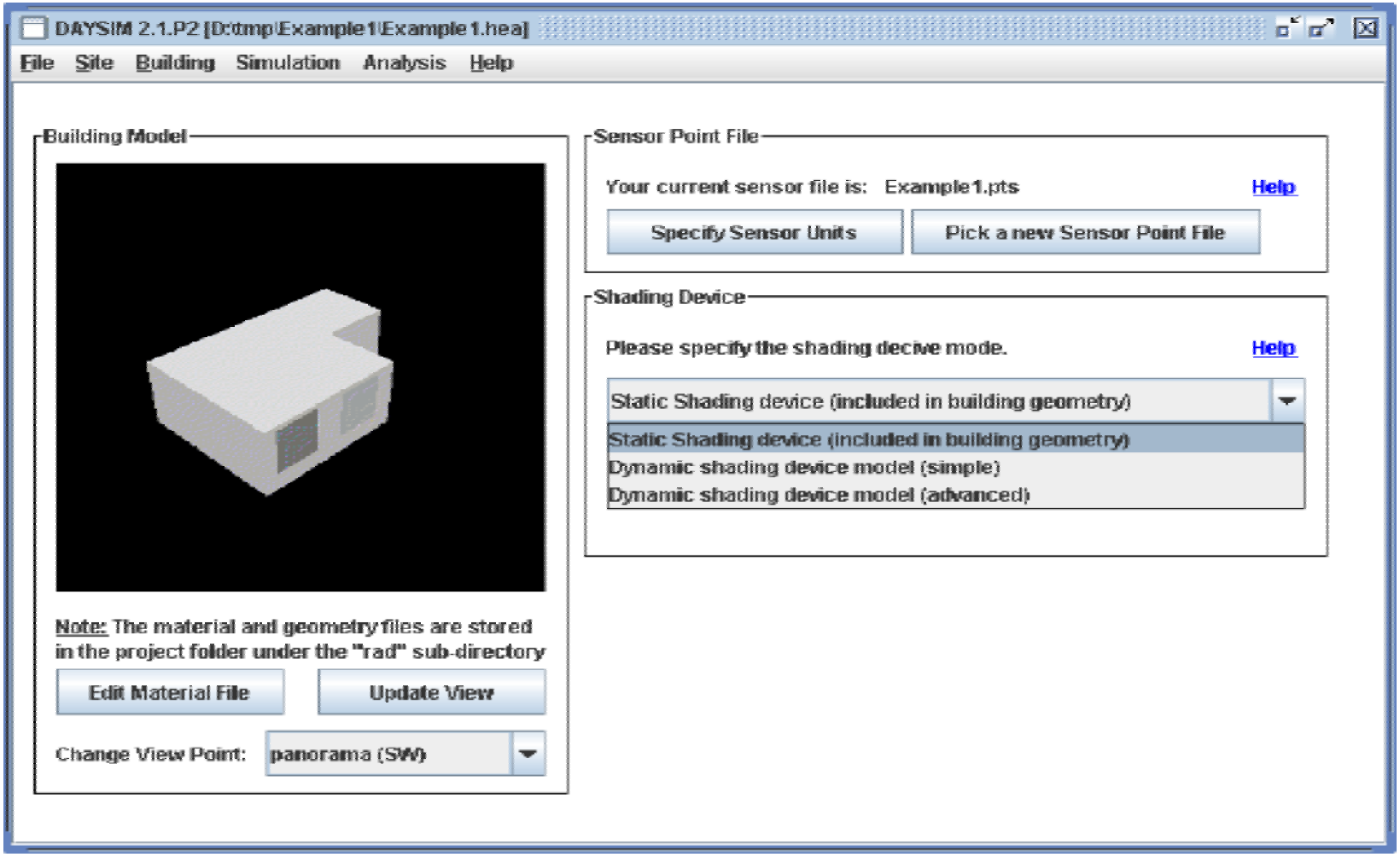
< 33%	33%-66%	66%-100%	> 100%
0%	46%	18%	36%

Width, [ft]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
26	93	94	59	44	53	86	92	61	42	47	77	94	71	40	32
24	70	67	64	58	58	66	69	60	56	55	63	69	60	48	45
22	54	56	55	52	56	60	59	57	56	55	58	54	54	46	46
20	43	45	49	48	47	50	48	47	47	50	47	45	44	42	37
18	33	36	38	39	40	38	40	38	39	39	36	36	35	33	30
16	26	28	32	31	32	32	33	32	32	31	33	30	30	27	26
14	26	24	25	28	24	27	28	26	26	25	25	25	24	24	22
12	21	20	21	23	23	22	23	22	22	22	22	21	20	20	20
10	18	18	19	19	20	20	21	20	20	20	18	18	19	18	17
8	19	16	17	17	17	16	17	17	17	17	17	16	15	15	15
6	14	13	15	15	16	15	15	14	14	14	15	14	14	14	17
4	14	14	14	14	15	14	14	15	13	14	14	13	14	13	13
2	15	13	14	15	15	14	17	15	16	17	15	15	16	13	14

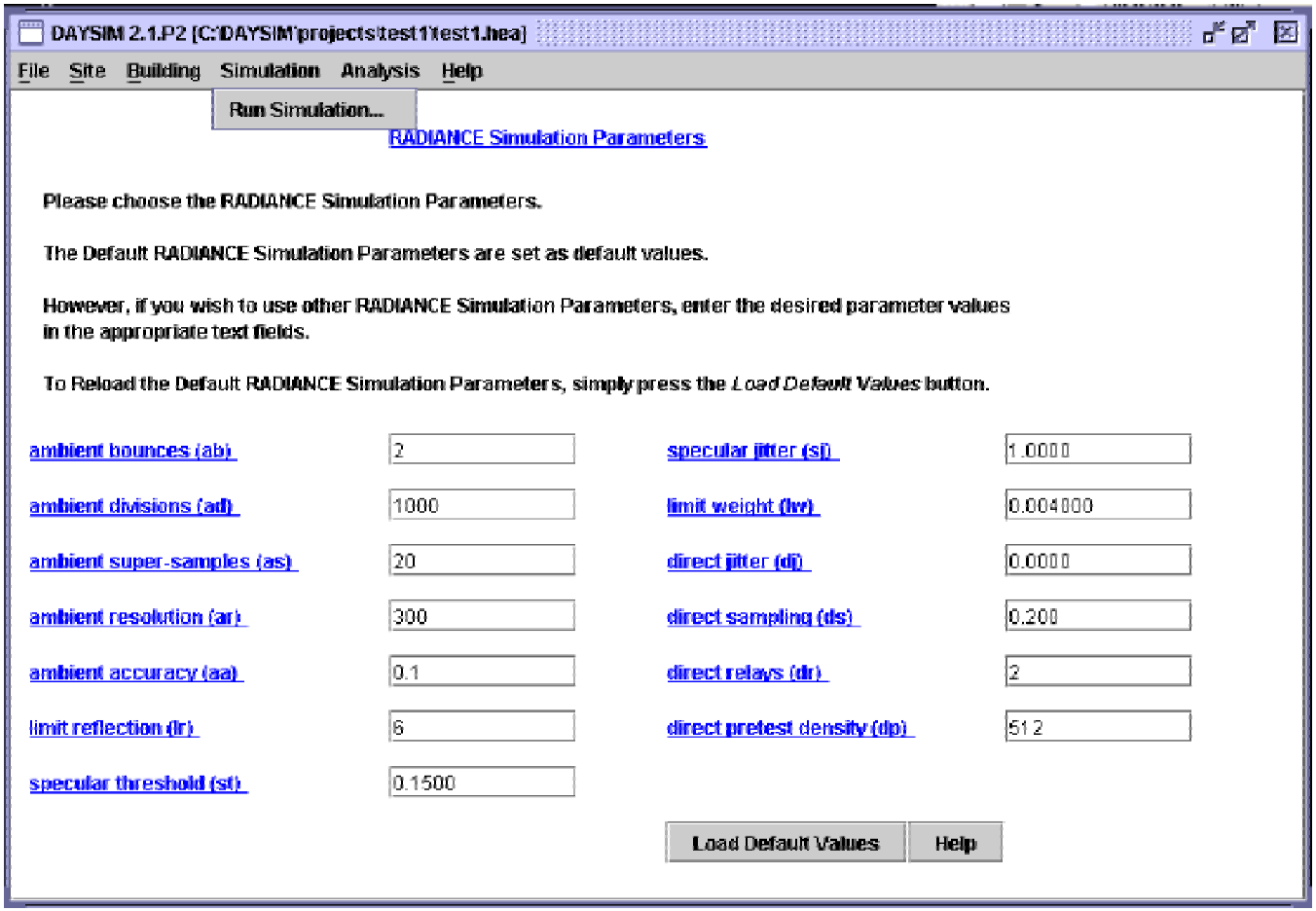
Length, [ft]



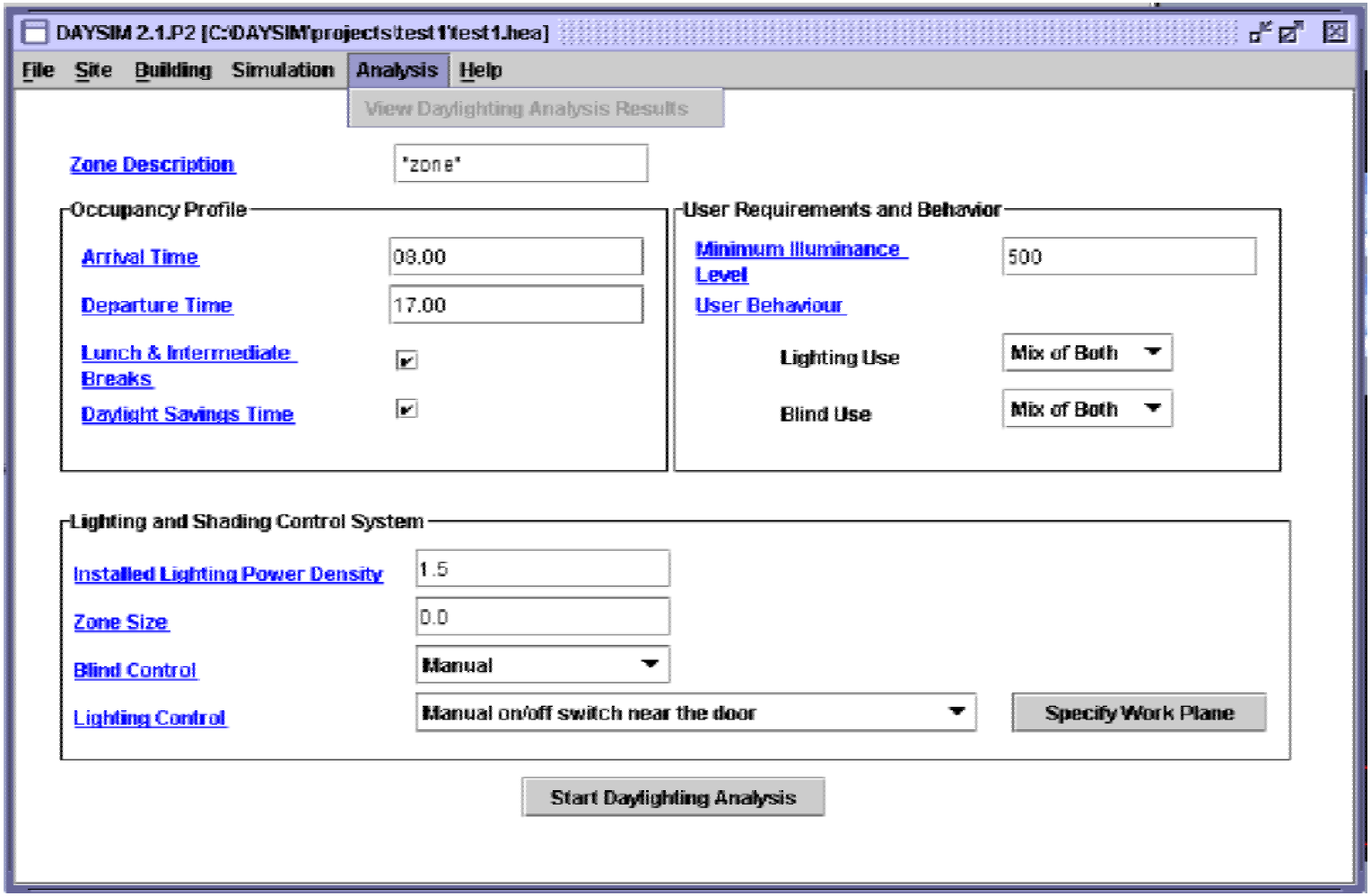
DAYSIM- Geometry Import



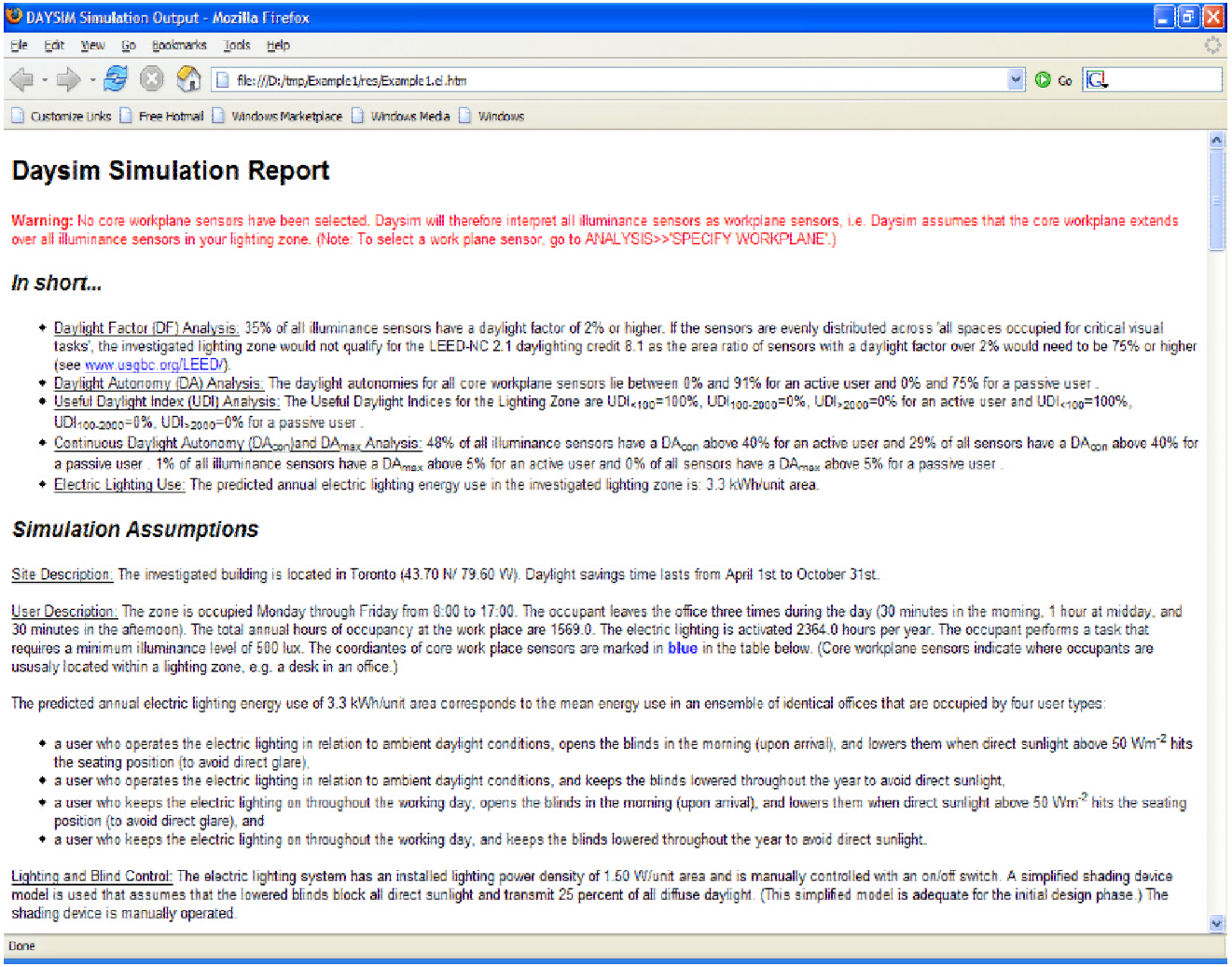
DAYSIM- Simulation Parameters



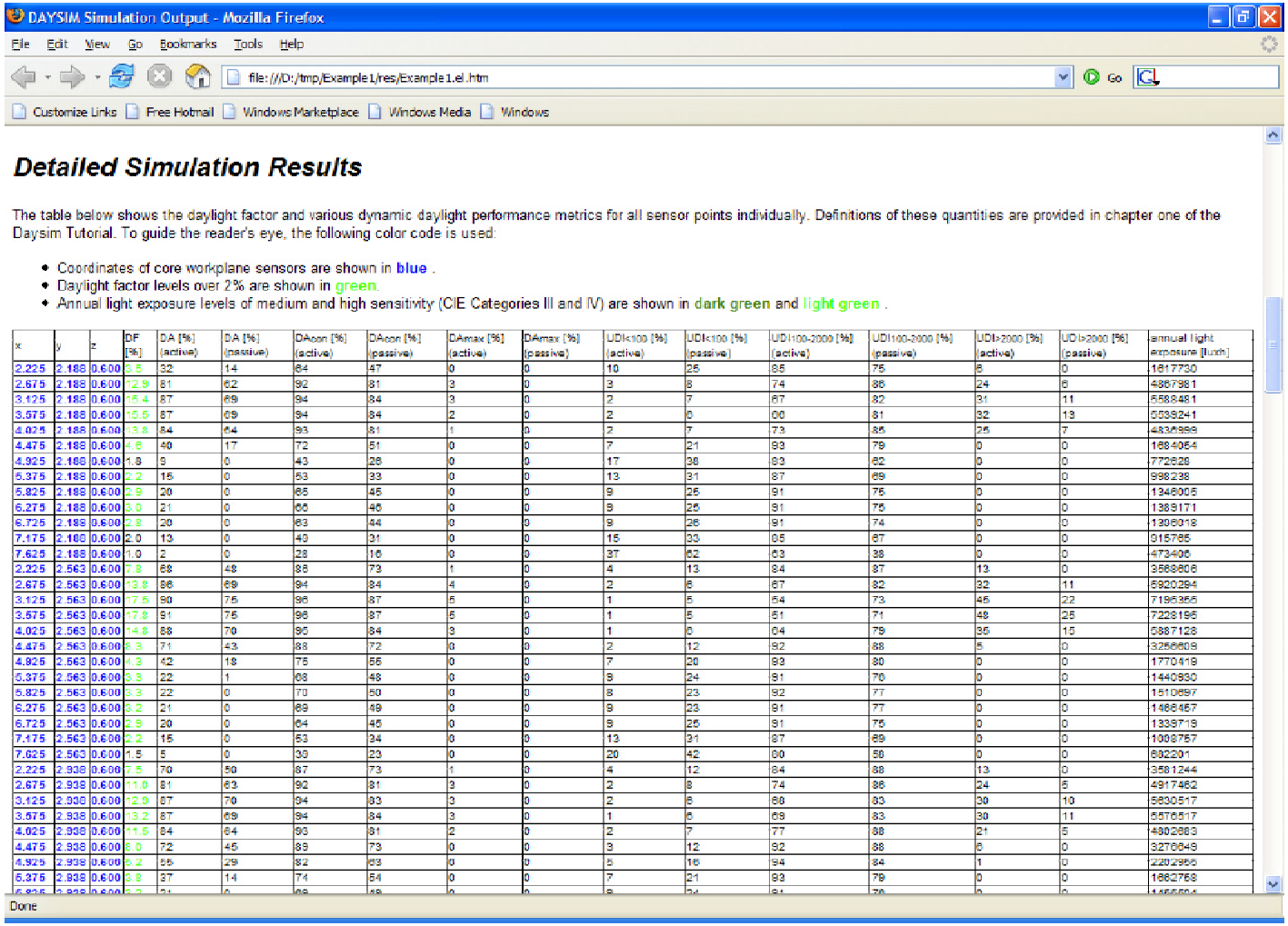
DAYSIM- Define Building Info



DAYSIM- Simulation Report

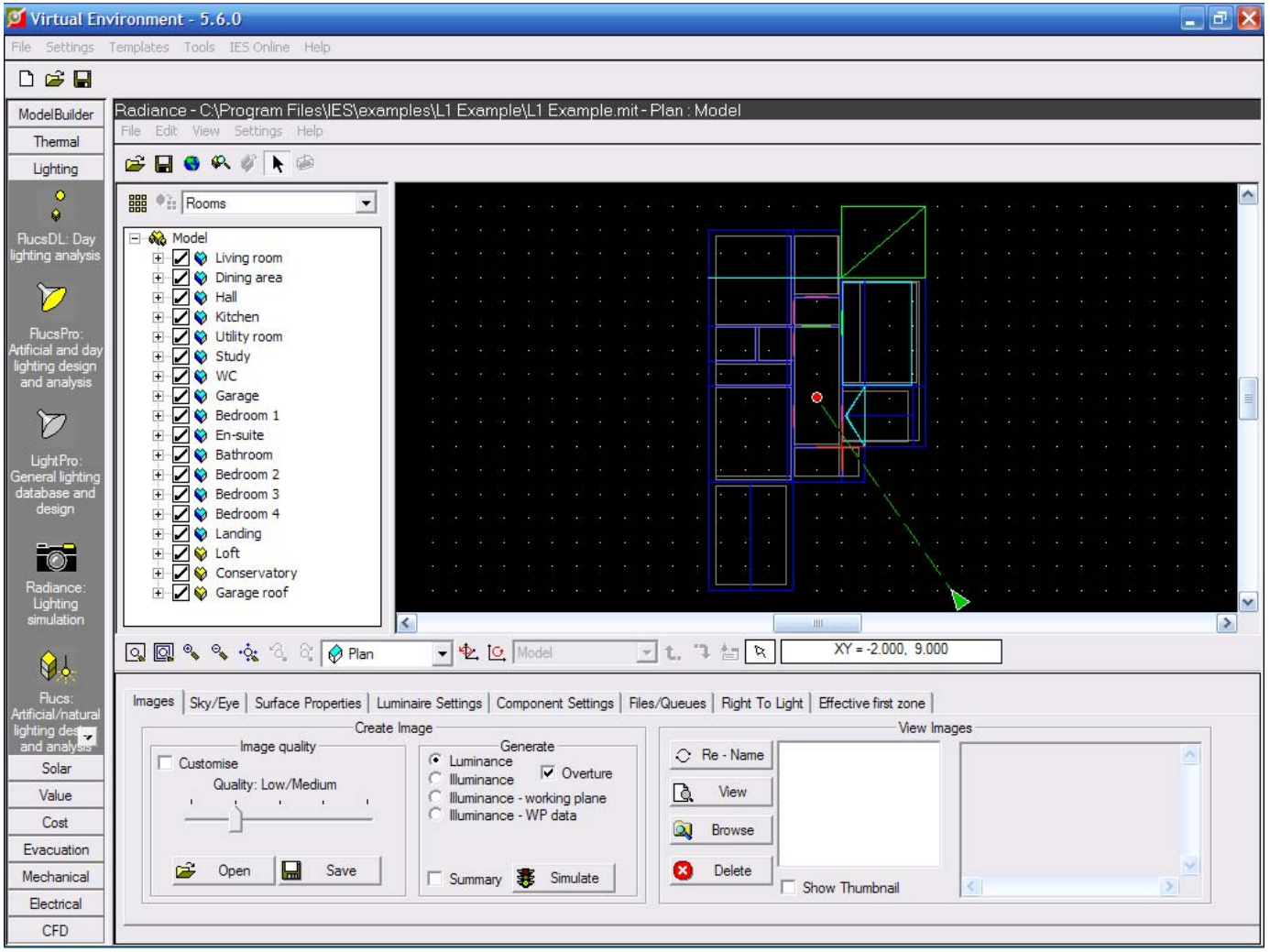


DAYSIM- Simulation Parameters (cont'd)

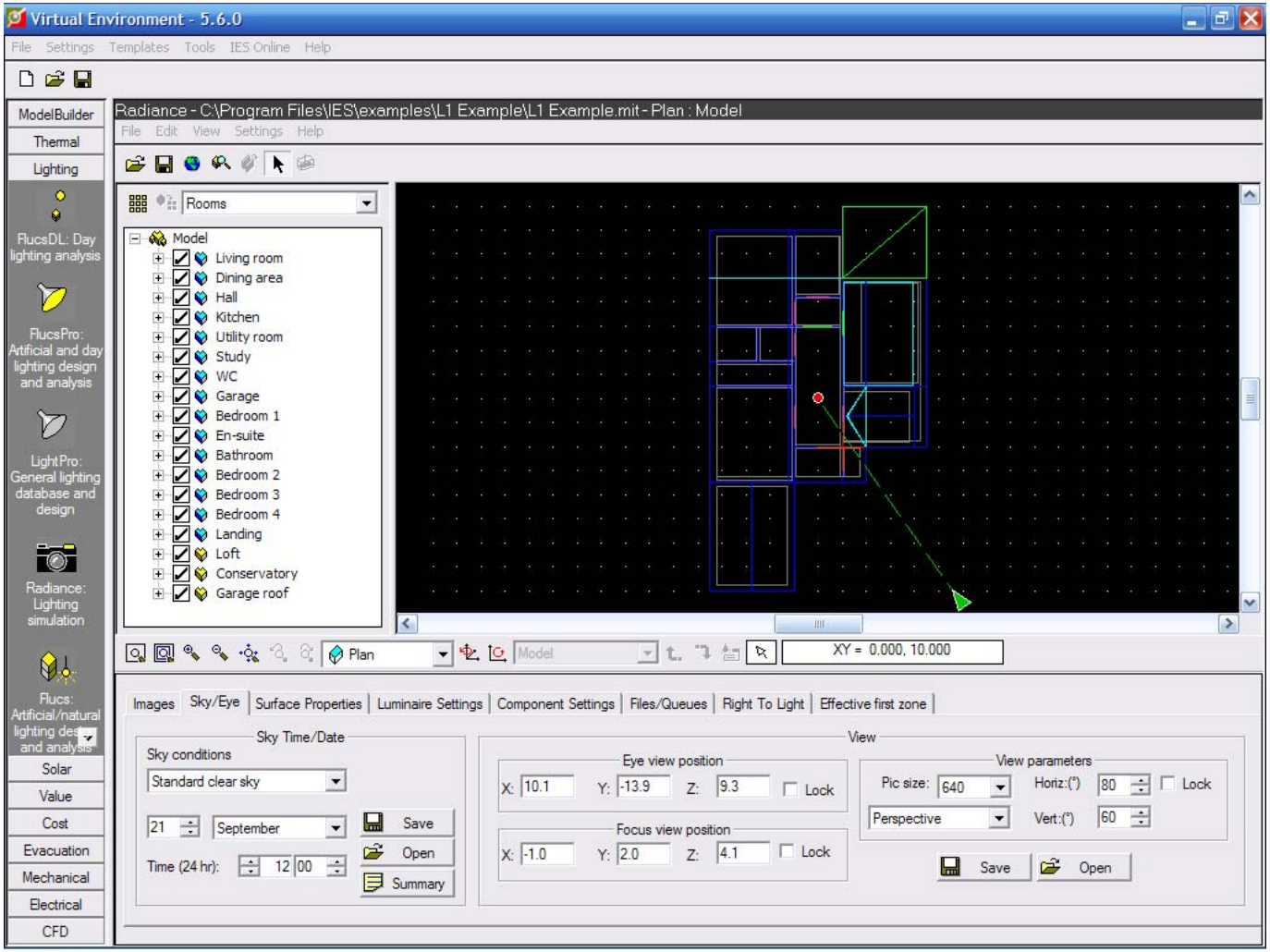


x	y	z	DF [%]	DA [%] (active)	DA [%] (passive)	DAcon [%] (active)	DAcon [%] (passive)	DAmax [%] (active)	DAmax [%] (passive)	UDI<100 [%] (active)	UDI<100 [%] (passive)	UDI100-2000 [%] (active)	UDI100-2000 [%] (passive)	UDI>2000 [%] (active)	UDI>2000 [%] (passive)	annual light exposure [lux/h]
2.225	2.188	0.600	3.5	32	14	84	47	0	0	10	25	65	75	6	0	1817730
2.675	2.188	0.600	12.9	81	62	92	81	3	0	3	8	74	86	24	6	4867981
3.125	2.188	0.600	15.4	87	69	94	84	3	0	2	7	67	82	31	11	5588481
3.575	2.188	0.600	15.5	87	69	94	84	2	0	2	6	66	81	32	13	5538241
4.025	2.188	0.600	13.8	84	64	93	81	1	0	2	7	73	85	25	7	4836988
4.475	2.188	0.600	4.6	40	17	72	51	0	0	7	21	93	79	0	0	1664054
4.925	2.188	0.600	1.8	9	0	43	26	0	0	17	38	83	62	0	0	772628
5.375	2.188	0.600	2.2	15	0	53	33	0	0	13	31	87	69	0	0	998238
5.825	2.188	0.600	2.9	20	0	65	45	0	0	9	25	91	75	0	0	1346005
6.275	2.188	0.600	3.0	21	0	66	46	0	0	9	25	91	75	0	0	1383171
6.725	2.188	0.600	2.8	20	0	63	44	0	0	9	26	91	74	0	0	1306018
7.175	2.188	0.600	2.0	13	0	49	31	0	0	15	33	85	67	0	0	915765
7.625	2.188	0.600	1.0	2	0	28	16	0	0	37	62	63	38	0	0	473496
2.225	2.563	0.600	7.8	68	48	88	73	1	0	4	13	84	87	13	0	3568808
2.675	2.563	0.600	13.8	86	69	94	84	4	0	2	6	67	82	32	11	5920294
3.125	2.563	0.600	17.5	90	75	96	87	5	0	1	5	54	73	45	22	7195355
3.575	2.563	0.600	17.8	91	75	96	87	5	0	1	5	51	71	48	25	7228196
4.025	2.563	0.600	14.8	88	70	95	84	3	0	1	6	64	79	35	15	5887128
4.475	2.563	0.600	8.3	71	43	88	72	0	0	2	12	92	88	5	0	3256608
4.925	2.563	0.600	4.3	42	18	75	56	0	0	7	20	93	80	0	0	1770419
5.375	2.563	0.600	3.3	22	1	68	48	0	0	9	24	91	76	0	0	1440830
5.825	2.563	0.600	3.3	22	0	70	50	0	0	8	23	92	77	0	0	1510697
6.275	2.563	0.600	3.2	21	0	69	49	0	0	9	23	91	77	0	0	1466457
6.725	2.563	0.600	2.9	20	0	64	45	0	0	9	25	91	75	0	0	1338718
7.175	2.563	0.600	2.2	15	0	53	34	0	0	13	31	87	69	0	0	1008757
7.625	2.563	0.600	1.5	5	0	33	23	0	0	20	42	80	58	0	0	692201
2.225	2.938	0.600	7.5	70	50	87	73	1	0	4	12	84	88	13	0	3581244
2.675	2.938	0.600	11.0	81	63	92	81	3	0	2	8	74	86	24	5	4917462
3.125	2.938	0.600	12.9	87	70	94	83	3	0	2	6	66	83	30	10	5830517
3.575	2.938	0.600	13.2	87	69	94	84	3	0	1	6	69	83	30	11	5576517
4.025	2.938	0.600	11.5	84	64	93	81	2	0	2	7	77	88	21	5	4802883
4.475	2.938	0.600	6.9	72	45	89	73	0	0	3	12	92	88	5	0	3276649
4.925	2.938	0.600	3.4	55	29	82	63	0	0	5	16	94	84	1	0	2202955
5.375	2.938	0.600	2.8	37	14	74	54	0	0	7	21	93	79	0	0	1862758

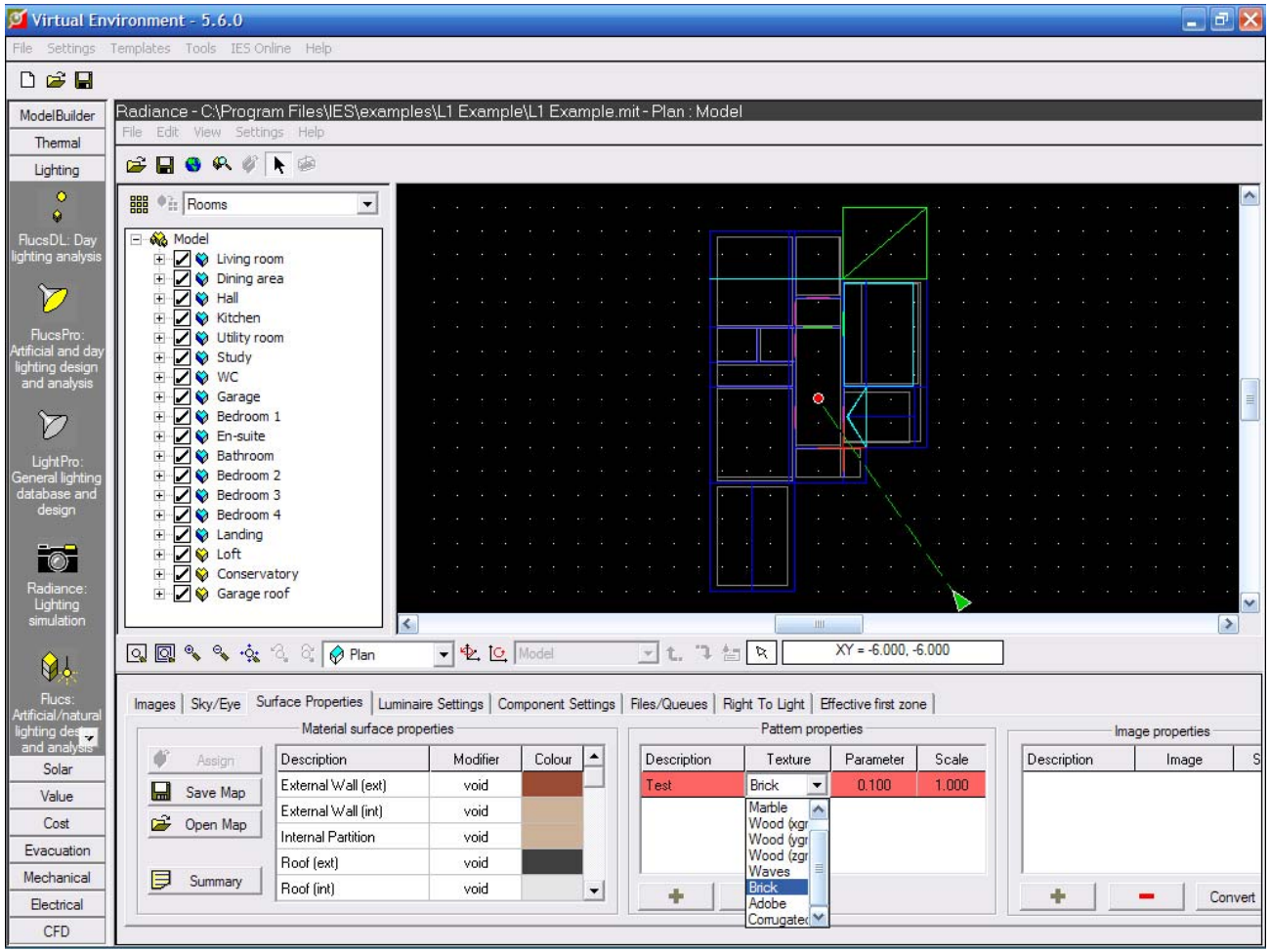
IES- Radiance



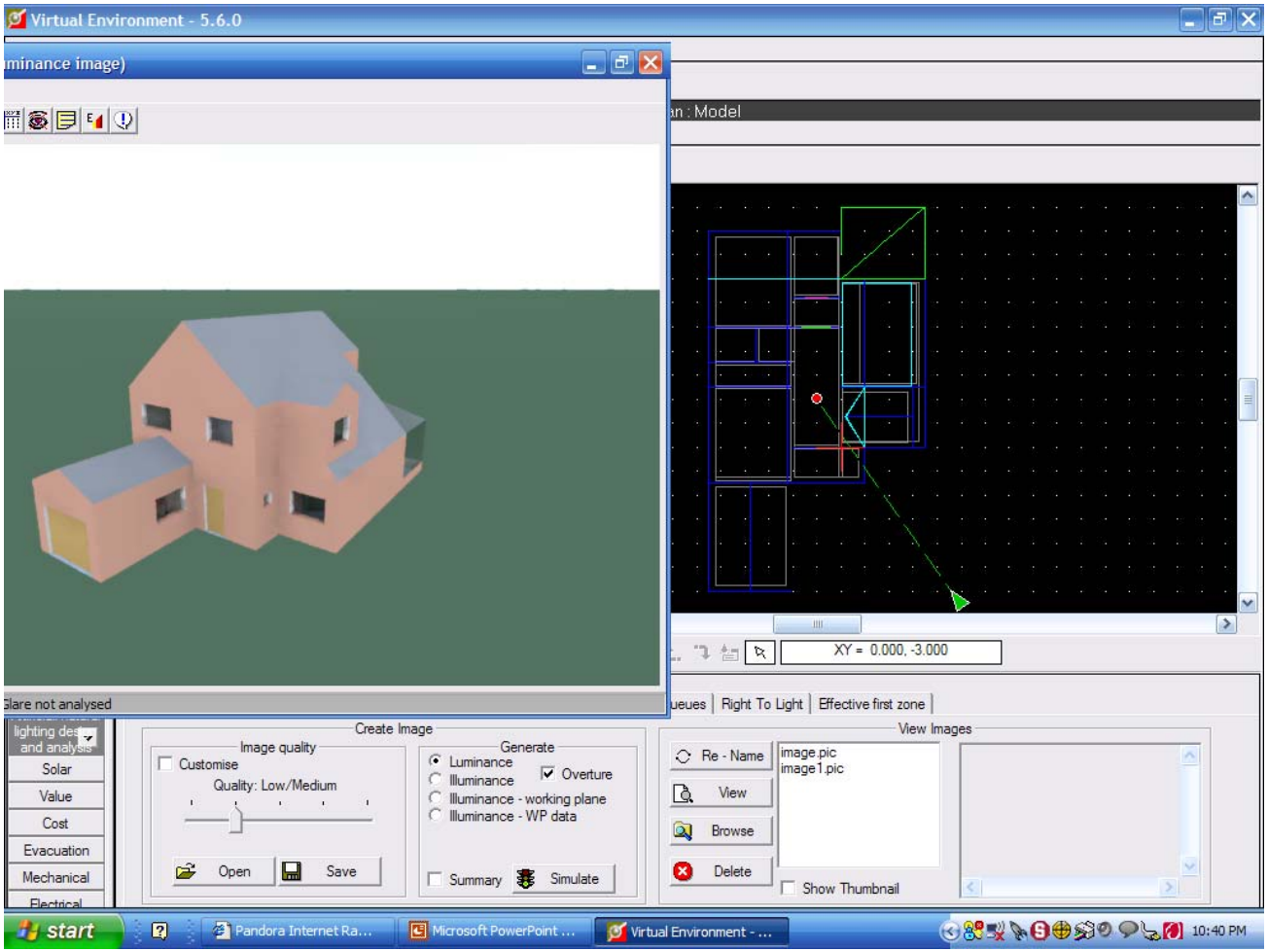
IES- Sky and Eye



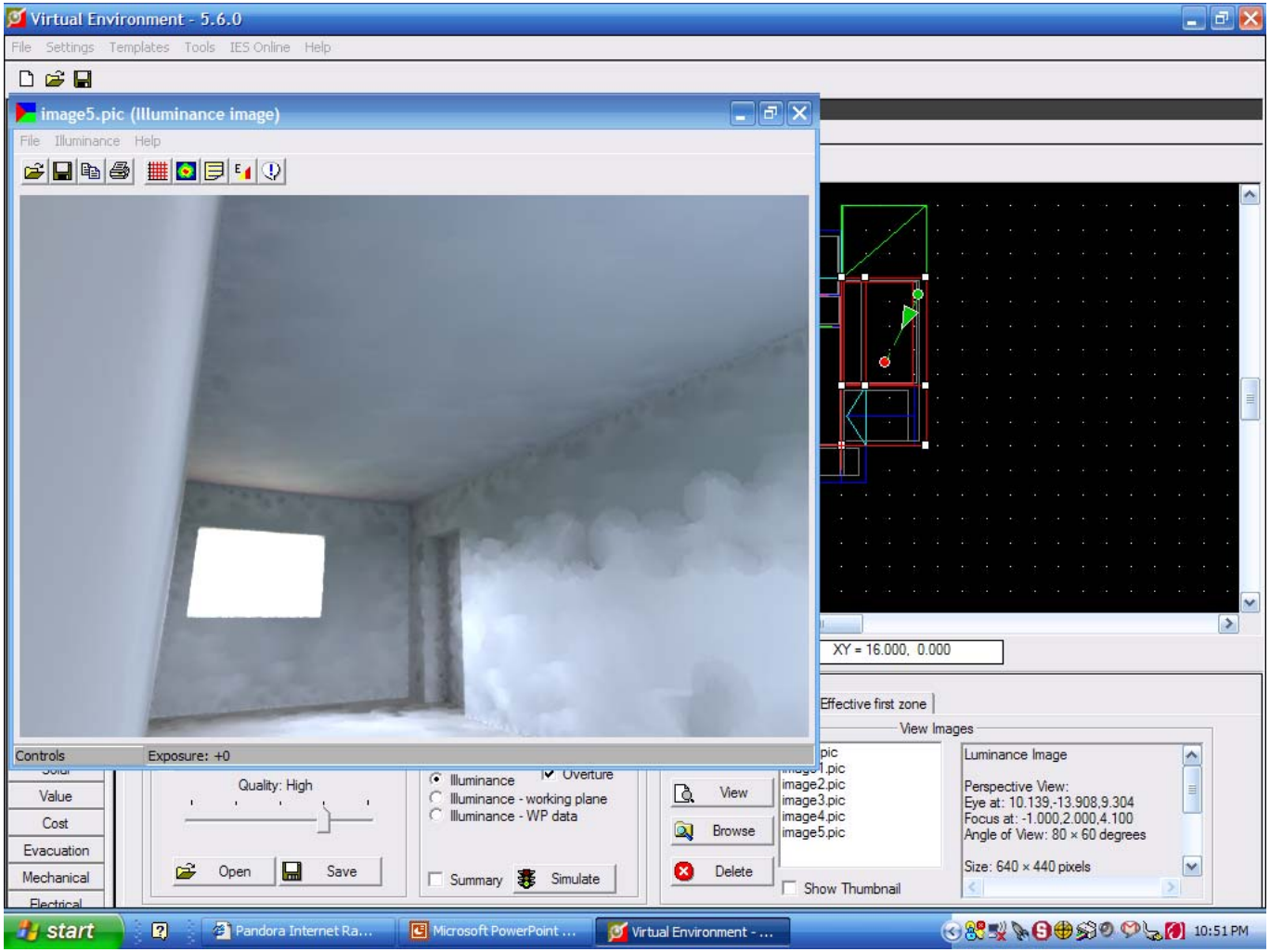
IES- Surface Properties



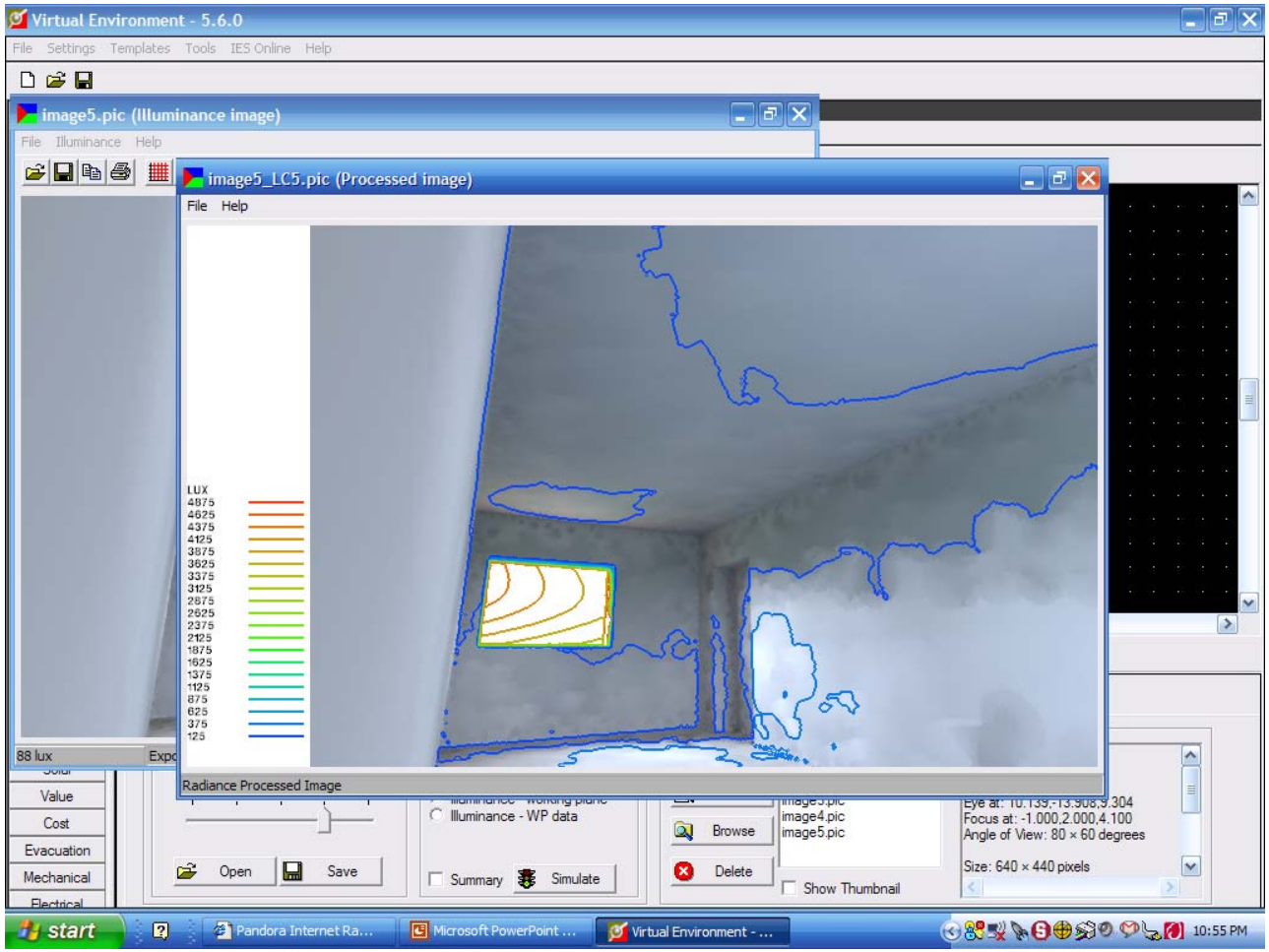
IES - Luminance Exterior



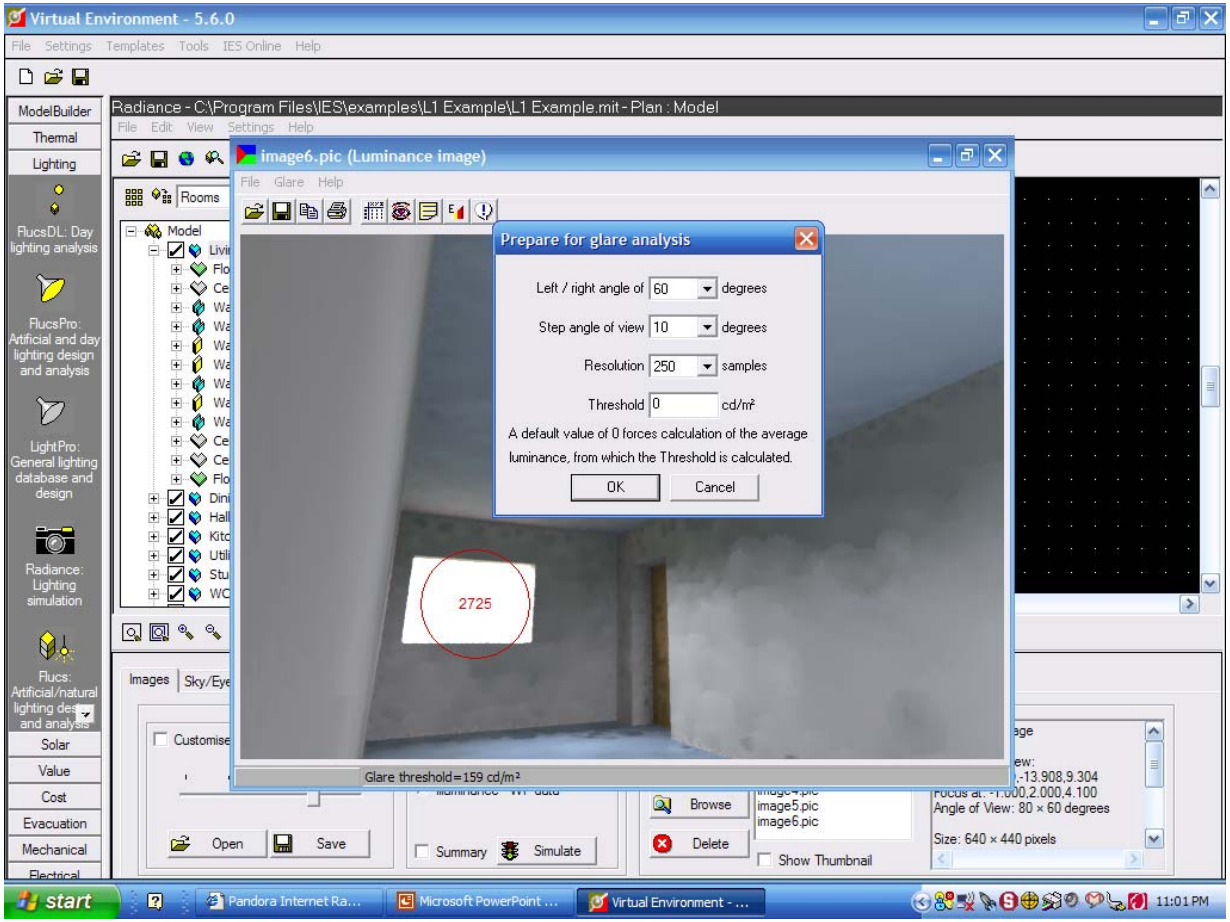
IES- Illuminance



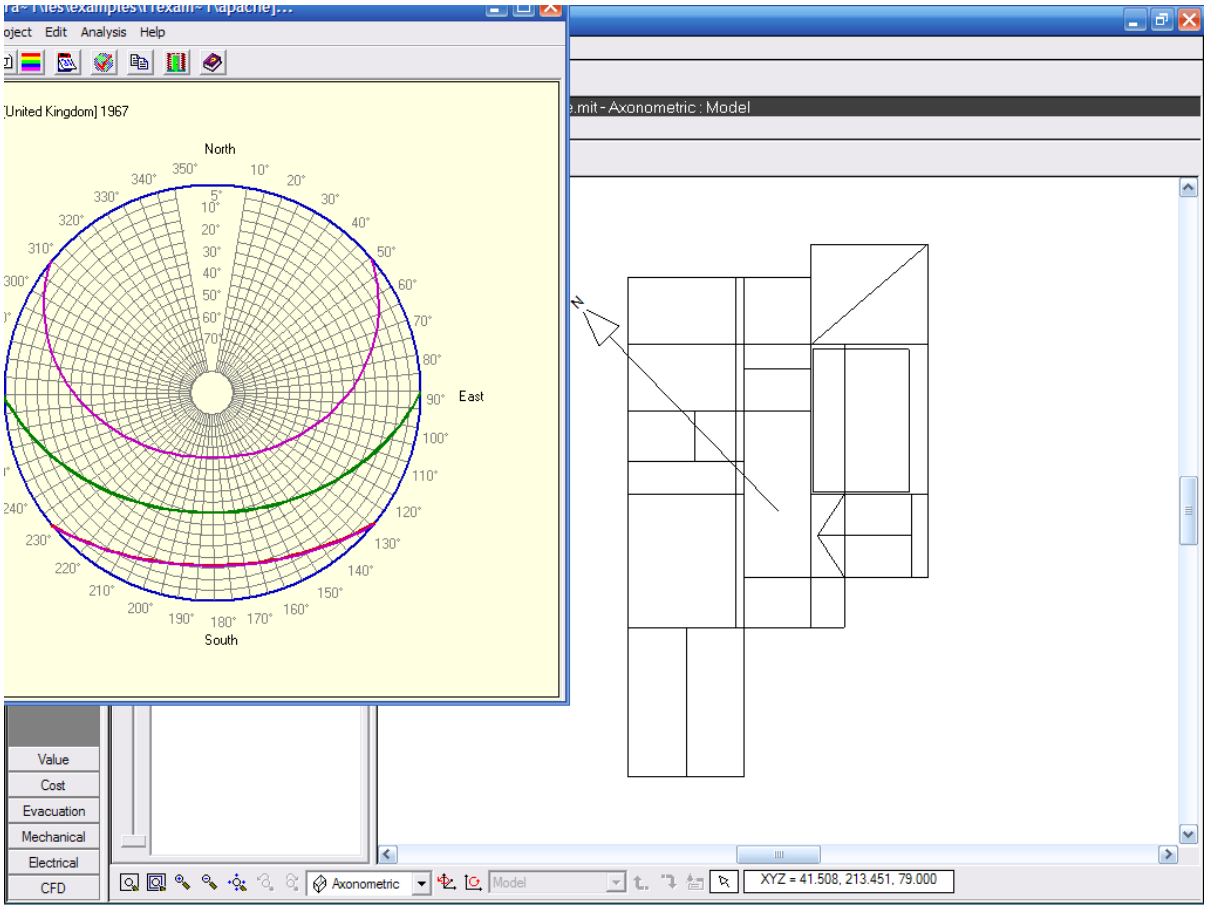
IES- Illuminance Contours



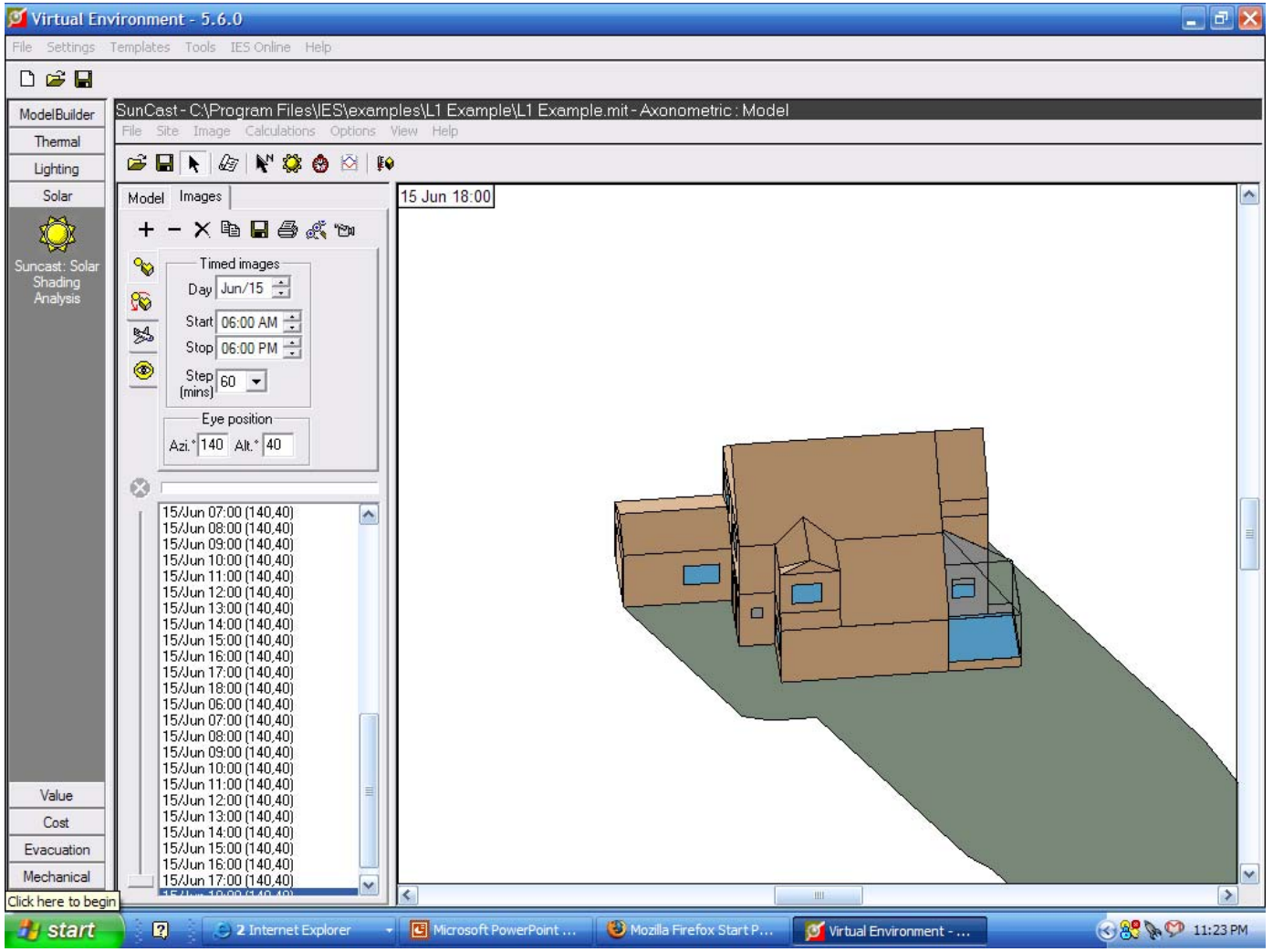
IES- Glare Analysis



IES- Sun Path Diagrams



IES- Shading Study



Questions?